ALLIS-CHALMERS

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S. R. Durand

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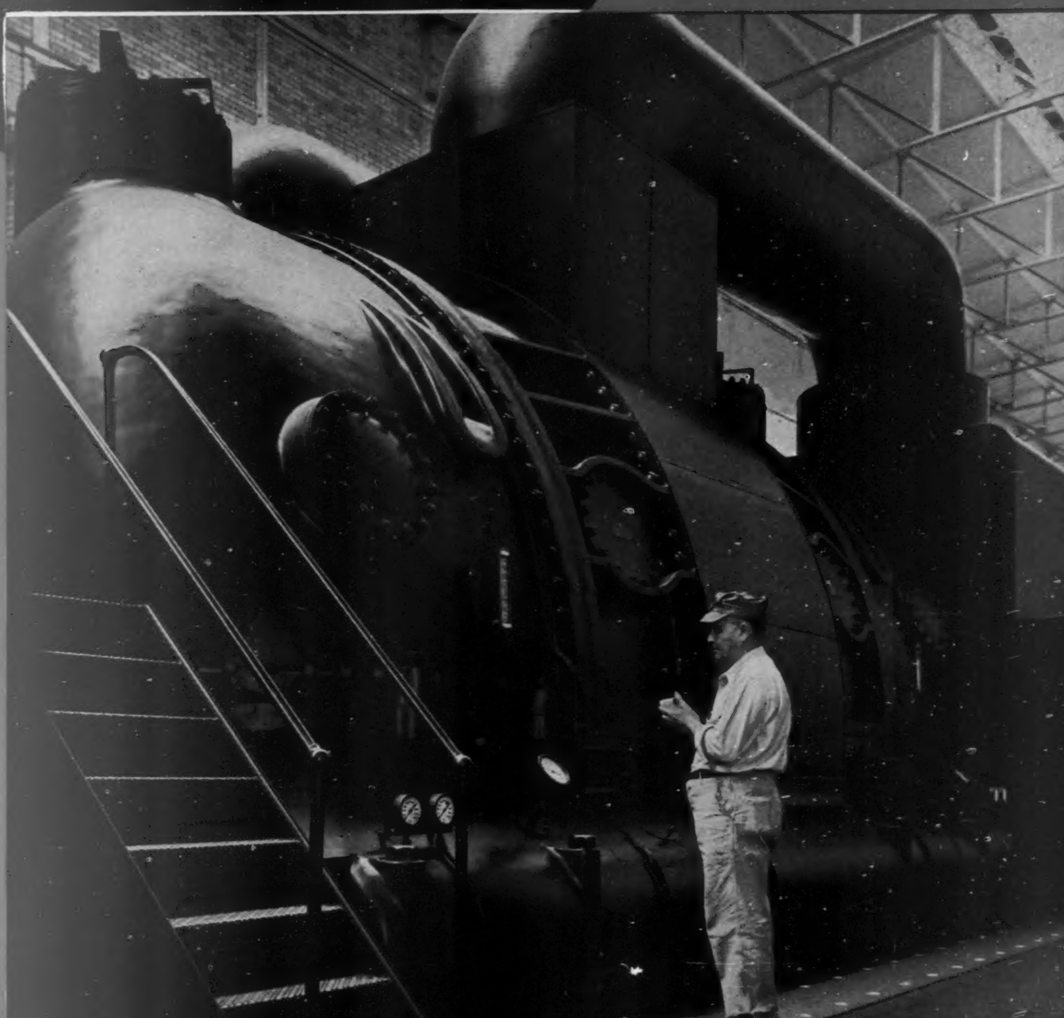

The largest turbo-generator to be installed in the United States since Pearl Harbor is this new 147,000 kw unit which is now in operation serving an important midwest war industrial area.

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ALLIS-CHALMERS

ELECTRICAL REVIEW

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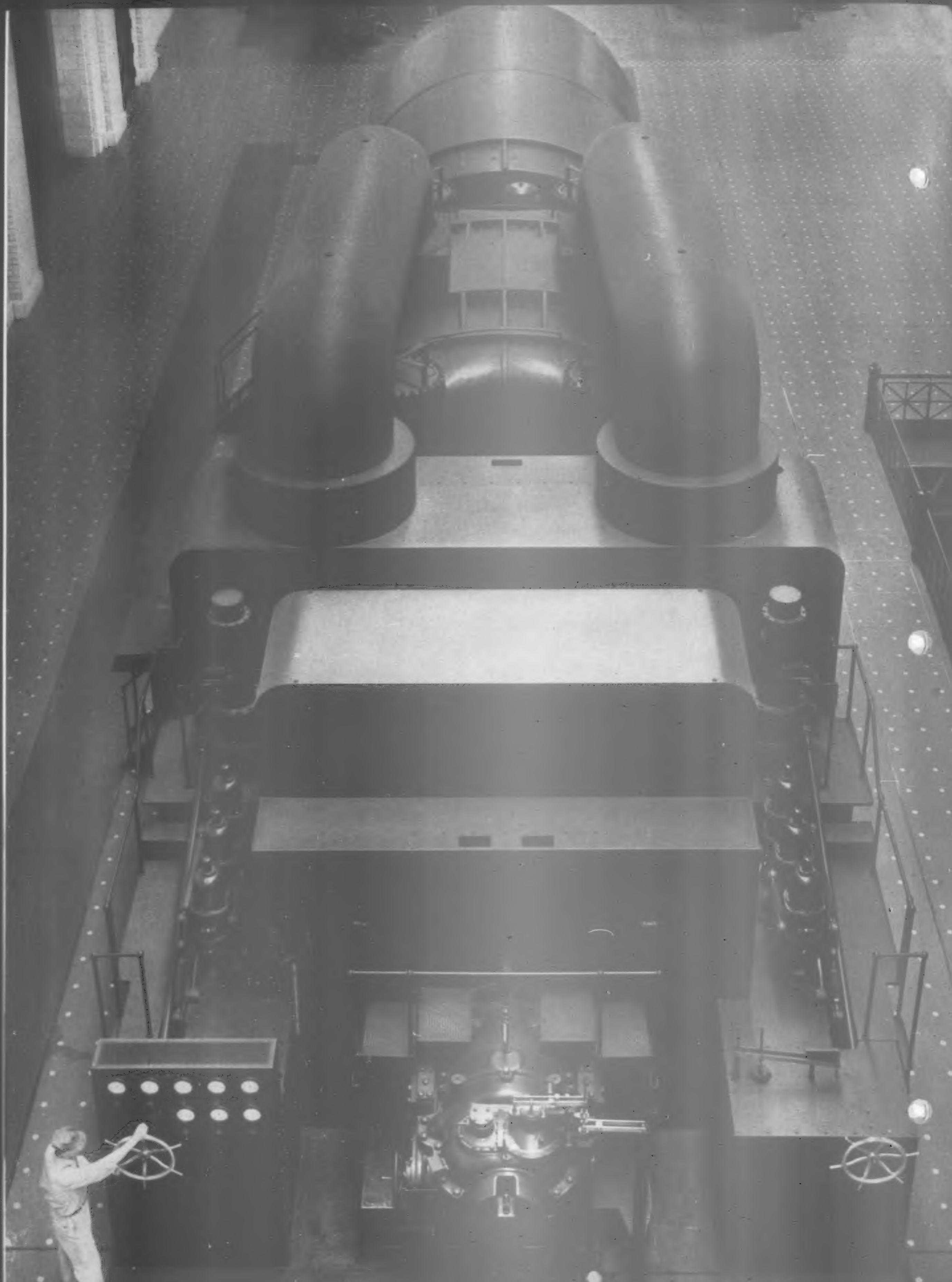


CONTROL THAT SPEED!

With the large adjustable speed drive increasingly favored by industry, very close speed control is sometimes necessary. For best control, consider these requirements

E. H. Fredrick and G. Byberg

MOTOR AND GENERATOR SECTION • ALLIS-CHALMERS MANUFACTURING COMPANY

Modern industry has been increasingly favoring the use of large adjustable speed drives which, at times, require very close control of speed. Since by far the largest percentage of electric power is generated in the form of alternating current, the most direct approach to a solution of the problem of speed control would be through the use of an alternating current motor. Unfortunately, alternating current motors inherently are not adjustable speed units, and in order to obtain satisfactory adjustable speed operation it is necessary that auxiliary equipment be used with this type of motor as an intermediary to provide speed characteristics approaching those of direct current machines.

Variable speed drives fall into two major classifications insofar as speed regulation is concerned. The first of these requires accurate speed adjustment and close speed regulation. This class includes such applications as metal rolling mills of the tandem type, some hot and cold strip mills, plating lines, sectionalized paper machine drives, wind tunnels, and drives for certain processing machines. The second type requires speed adjustment but no particularly close speed regulation. Installations such as marine or locomotive propulsion equipment, mine hoists, reversing rolling mills, centrifugal casting machines, and forced and induced draft fans fall into this category.

The torque characteristic of the load is another important factor to consider. In general, it might be said that there are three types of load characteristics: (1) the constant torque drive, in which the torque required by the driven unit remains practically constant regardless of speed, (2) the constant horsepower drive, in which the torque required by the driven unit will decrease in a direct ratio with an increase in speed, (3) the variable torque drive, a characteristic common to most centrifugal devices, such as propeller or blower loads in which the torque increases as an exponential function of the speed.

AT LEFT: Installed recently for a midwest utility, this Allis-Chalmers turbo-generator is 12,600 v. 3 phase, 60 cycle, 80 percent pf, 1,800 rpm, air-cooled. One of the world's largest single-shaft turbines, it operates at steam pressure of 1250 psi and temperature of 925° F.

A variable torque characteristic is not inherent in an electrical machine. It is, therefore, essential that, for loads of this type, a constant torque drive, the closest approach possible electrically to a variable torque characteristic, be applied.

The question of shock loading and stability is closely allied with the classifications mentioned above. A load with a variable torque characteristic is usually inherently stable and free from impact loads. Constant horsepower and constant torque drives, on the other hand, are usually susceptible to peaks in the torque demand. In some cases it is essential that the control compensate for the effect of wide, rapid load swings while in others this fluctuation might be relatively unimportant.

Speed control considerations

In considering the relative merits of the various systems of speed control, the major points to be considered are these:

1 — Range of speed to be covered.

2 — Speed regulation requirements and accuracy of control for this purpose.

3 — Simplicity of control.

4 — Overall operating efficiency.

5 — First cost of machines (and buildings due to space requirements).

6 — Dependability, as determined by the number and types of machines involved.

7 — Maintenance.

The relative importance of these individual items depends, to a large extent, upon the final goal to be attained. For example: if an extreme speed range with control of speed over this range is essential, the items of first cost and efficiency may become subordinate to the interest of obtaining that operating characteristic. On the other hand, for certain drives, the efficiency may be paramount while wide speed range is not required, therefore an entirely different type of drive may be indicated for this function.

Since it is obviously not possible here to cover all of the adjustable speed drives now available, only the more common types will be discussed, as enumerated:

1 — Direct current machines.
2 — Variable frequency drives.
3 — Kraemer and Scherbius systems.
4 — Other types frequently used.

Besides the above mentioned adjustable speed systems there are various kinds of commutator type a-c machines which are, in general, limited to the smaller sizes.

Direct-current drives

Another prominent motor trend for many years was toward the use of alternating current motors wherever possible. During and immediately preceding the present war emergency, the direct current drive has made a remarkable comeback. Statistics show that between the years 1936 and 1942, direct current machines more than doubled their percentage relative to the total horsepower of motors manufactured in those years. The performance requirements for modern drives have become more stringent and the direct current motor is ideally suited to meet these higher standards. The inherent ability of the direct current motor to provide relatively simple means of accurate speed control has successfully overcome, in many instances, the disadvantages of higher first cost and possibly slightly lower efficiencies at full speed.

When the installation of an adjustable speed drive is being considered, a direct current motor is practically always one of the contenders for the job. In fact, in many applications a direct current motor is the only feasible choice. The direct current motor is unique among electric drives in that its speed may be regulated closely, either by varying the strength of its field or by changing the voltage applied across its armature. Besides these obviously advantageous characteristics, the speed regulation (variation of speed with load) can be conveniently altered by the use of special fields or automatic control to provide almost any desirable speed-load characteristics.

The most common and the simplest means of obtaining speed adjustment on a d-c motor is either varying the applied armature voltage or varying the amount of field current or both. By means of proper control, a direct current motor can be operated at any speed from standstill to its maximum rated speed and the adjustments between these two limits may be made readily in very small steps.

In general it may be said that direct current drives are becoming increasingly popular (1) where a very wide speed range is essential and (2) where a very fine control of speed at any point in the range is required. In many cases close speed regulation is not required, but operation at any of a widely varying number of speed points is desirable. For such application, the speed control of the direct-current motor is the simplest.

Field weakening

The permissible speed range by field weakening is dependent upon a number of factors, such as base speed (full-field), mechanical construction, commutation, consideration of stability at weak field and the characteristics of the load.

The smaller the motor and the lower the base speed, the greater is the possible speed range, although this will usually be limited to a ratio of 6 to 1 because of instability and speed regulation complications at any further weakening of the field. With increasing size and higher base speeds this ratio gradually decreases until a point is reached where both electrical and mechanical limitations prohibit further increase, that is, where no increase above base speed by field weakening is permissible and the ratio becomes 1 to 1.

A fundamental characteristic of the adjustable-speed d-c motor is that it has a constant horsepower capacity over the field-weakening speed range. Since the torque is a function of armature current and field strength, the weakening of the field (i. e., the reduction of flux in the magnetic circuit) produces a corresponding reduction in the torque. And since the speed is inversely proportional to field strength the result is that torque times rpm is constant, or for practical purposes, very nearly so.

Practical values of maximum speeds for various ratings of standard commercial machines are shown in Fig. 1. From a study of these curves it will be noted that, as the horsepower rating increases, the limiting speed value in rpm decreases. This is due primarily to mechanical limitations. With larger horsepower ratings a larger commutator is required, and limitations inherent in its operation, such as peripheral velocity and rubbing velocity at the brushes — prevent going beyond certain limits established by design and operating experience.

Shunt wound motors

Shunt wound motors are applied to constant speed drives having approximately constant torque load, and are used in applications of light load or low inertia starting where very heavy starting torque is not required. Motors with shunt characteristics are used in adjustable speed applications. Up to 2 to 1 speed range, straight shunt wound motors are used, and above 2 to 1 range a very light series winding known as a stabilizing winding is used. This winding consists of a very few turns connected in series with the armature. Its purpose is to insure stability of motor speed under weakened shunt field conditions, and its effect is cumulative with that of the main field. It also serves to prevent hunting, inherent with the combination of extremely weak field and fluctuating load conditions.

Shunt wound motors should not be applied to constant speed drives such as fans or blowers where there is a definite tendency for the supply voltage to rise to values above normal. Large shunt motors with rising load-speed characteristics should not be applied to such loads nor to inertia or propeller loads as there will be a decided tendency toward racing or instability.

The compound wound motor has, in addition to the shunt winding, a series winding carrying the normal armature current. This series winding is ordinarily connected so as to be cumulative; that is, it produces magnetization in the same direction as the main shunt winding. Then, any tendency to increase speed due to

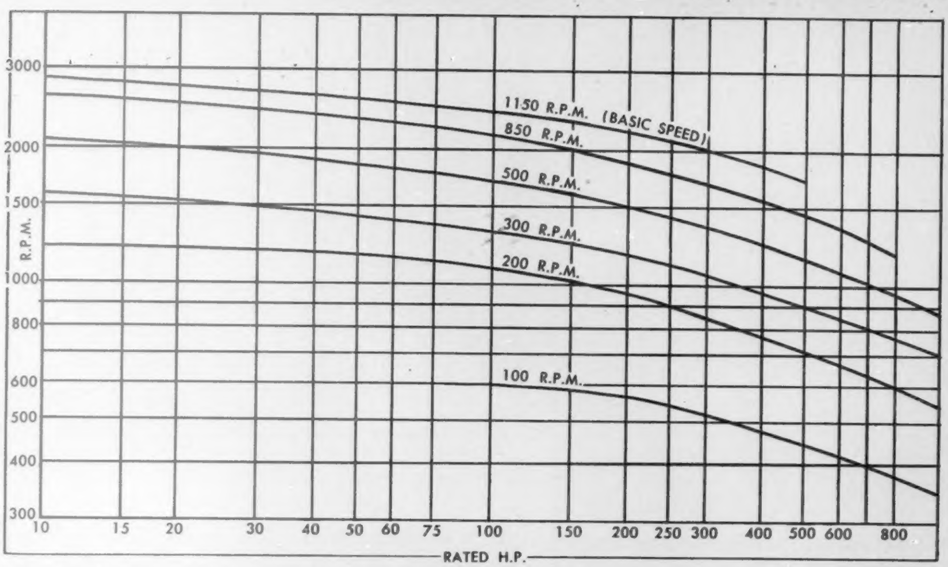


Fig. 1 — Maximum values of speed obtainable by field weakening for d-c motors of various basic speed ratings.

rise in supply voltage and accompanying increase in load will be counteracted by the increased armature current through the series winding producing greater field magnetization and preventing speed rise. Consequently this type is used for such drives as constant speed fans, pumps, or blowers, where the motor is subject to these voltage fluctuations, or for constant torque drives, where, for some reason inherent in the drive itself, it is desired to have an appreciably lower speed at full load than at no load. This would be true of elevator motors, for example, where high starting torque is required but where the series winding may be shorted out by the control under adjustable speed operation after the motor is up to speed.

Motors with any appreciable speed range by field control are not recommended compound wound, unless for very specialized applications. Weakening the shunt field increases the percentage of total flux furnished by the series field so that, at weakened field, the motor characteristics approach those of a series motor with light shunt field to limit the no-load speed and with consequent poor speed regulation.

Armature resistance

Possibly the simplest and the cheapest method of controlling the speed of a direct current motor below its basic rated speed is the use of adjustable resistance in the armature circuit. This method is especially practicable when it is necessary to operate the d-c motor from a constant voltage source. In this case a starting resistance is required, and if the the thermal design of the starter is such as to allow continuous duty, it can be used for speed control.

However, three major disadvantages offset the advantages of the low first cost and simplicity, especially in the larger drives. In the first place, the speed regulation of the motor has a decided drooping characteris-

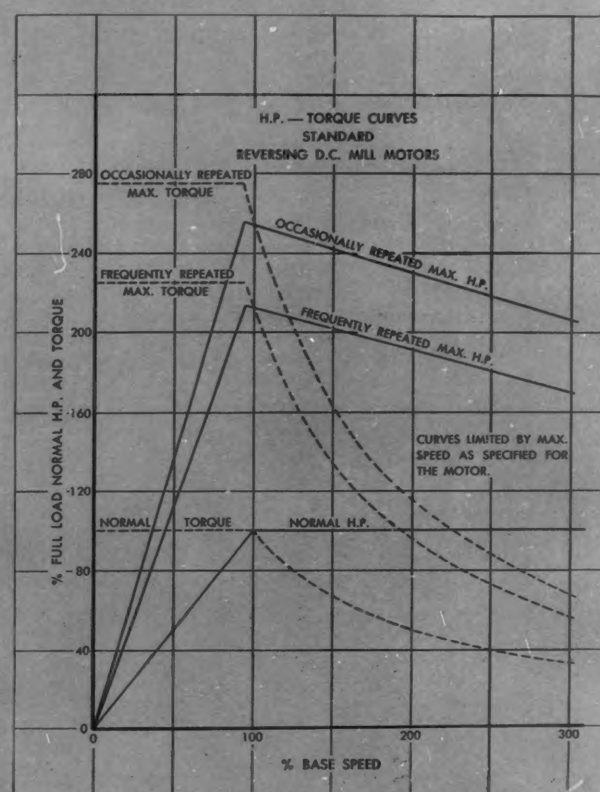


Fig. 2 — Capacity of a heavy duty motor controlled by a combination of armature voltage and field controlled system.

Fig. 3 — Wide speed range d-c motor for planer drive uses combination of variable voltage and field weakening.

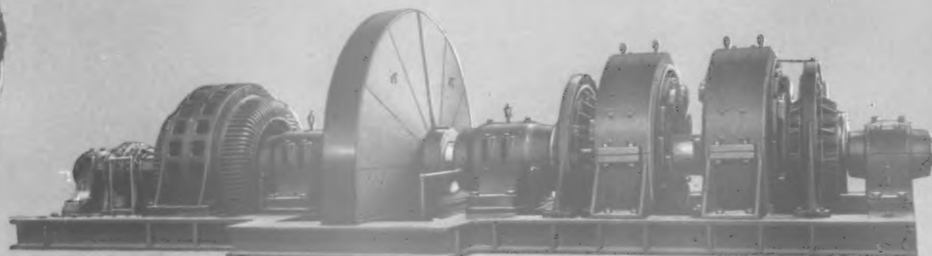


Fig. 4 — Induction motor-flywheel-generator set supplying variable voltage to non-reversing or reversing motors with highly fluctuating loads.

tic because the voltage across the motor armature terminals will decrease as the IR drop across the resistor increases with an increase in load current. Second, for the same reason the losses in the resistor are very large at reduced speed operation. Third, the speed selection is limited by mechanical construction of the resistor control and unless a very special design is utilized, the number of speed points is usually less than eleven.

In general we may say that armature resistance speed control is limited to drives of less than 50 hp with a short operating cycle, where close speed regulation is not a requirement. Elevators, cranes, traction equipment, and similar loads are representative of this type.

Variable armature voltage

The fact that the speed of a direct current motor will respond readily to a change in armature voltage permits the extensive use of the variable armature voltage system of speed control. This system lends itself particularly to automatic control, and in many instances allows a fineness and range of control possible with no other type of drive. The necessary use of an individual generator to support the direct current motor makes the first cost of the equipment relatively high, but the advantages obtained in many cases outweigh this disadvantage.

The recent introduction of rotating type regulators has given added impetus to the so-called Ward-Leonard system of speed control. By means of these devices, speed, torque, voltage, or any other factor which can be measured electrically can be controlled. The major advantage of this type of control is the fact that control amplification is very high. An impulse of a few watts easily controls the output of thousands of horsepower. As an example, a 5,000 hp reversing mill motor can be automatically controlled to reverse its rotation from basic rated speed forward to basic speed reverse in less than two seconds. This reversing function is accomplished with control of current in the armature circuit to a maximum of less than 225 percent of normal current. The rotating regulator, a regulating exciter in this case, operates in the excitation circuit of the generators, supporting the reversing motor and providing automatic regenerative braking to bring the motor to a stop. It also provides automatic current controlled acceleration to bring it up in the reverse direction.

Fig. 5 — This 7,000 hp, 700 volt reversing motor for blooming or slabbing mill service has a speed range of zero to 40 rpm by variable voltage and 40 to 100 rpm by field weakening.

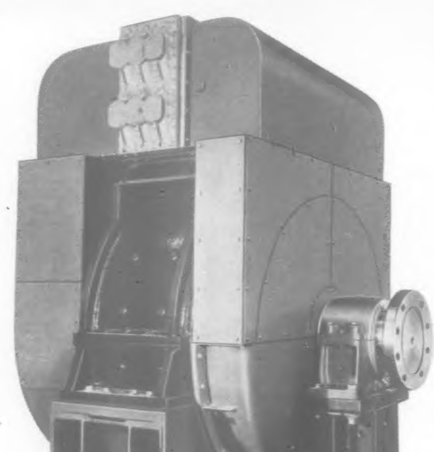


Fig. 6 — In marine service this large 600 volt, totally-enclosed self-ventilated motor is used for variable voltage propulsion.

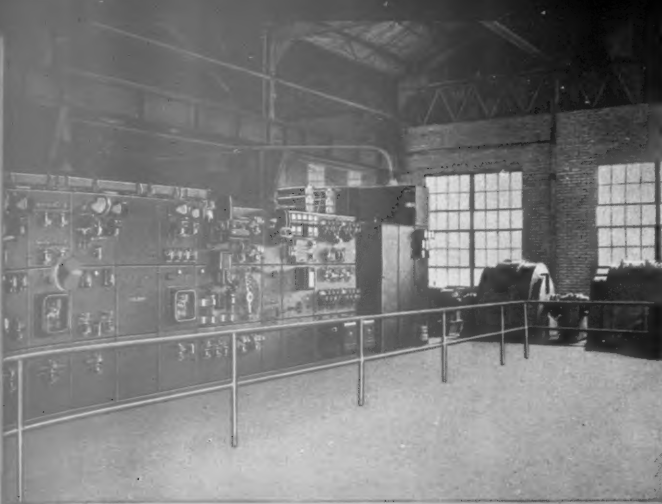


Fig. 7 — Control for a single-stand temper pass mill.

The recent exploitation of electronic control has still further broadened and increased the accuracy of this type of control. Speed and voltage controlled quantities, fantastic a few years ago, are now becoming relatively commonplace, with the use of electronic control circuits.

To a limited extent, the use of both rotating regulators and electronic control in the field circuit of d-c motors also has been advanced. By means of these new control devices, accuracy and speed of response of the motor to its control impulse has reached limits impossible to attain even a few years ago.

To use these new and highly accurate controls effectively, it is necessary to coordinate the design of the generators, motors, control, and exciters, and to design the combination as an integral working unit. Many characteristics can be incorporated in the design of the machines to facilitate the functioning of the control, and when a complete job is engineered advantage must be taken of all such available features.

Armature voltage and field weakening

In many applications of d-c motors, it is necessary to operate at very low speeds, or to start or reverse very frequently. If this stipulation is combined with necessity for a very wide speed range where the horsepower requirement remains constant or even decreases above certain speeds, a combination of armature voltage and field controlled system is indicated. Reversing rolling mills and mine hoists are representative of this type of loading.

The capacity of a heavy duty motor for this type of service is illustrated in Fig. 2. From zero speed to basic speed the motor operates on a reduced armature voltage and a full field. Above basic speed the motor is supplied with full armature voltage and its field is weakened. Note that above the normal rating of the machine the base speed decreases slightly. This decrease in speed is caused by the natural speed regulation of the motor when overloaded. The design and operation of d-c drives as well as the other adjustable speed drives mentioned entails many more factors than those here enumerated. Further detailed explanation of these features will be fully treated in a subsequent article.

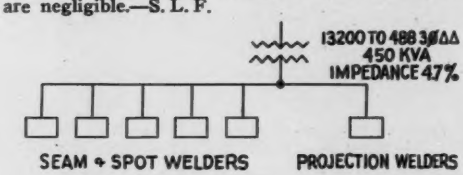
WHAT'S THE ANSWER?

Question—What is the function of switchgear in an electrical circuit?—R. J. K.

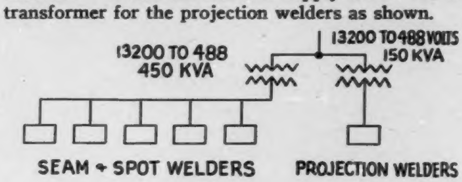
Answer— Switchgear in an electrical circuit is the equipment comprising a switching point. Electrical power is received from the supplying source, such as a generator or a supply line, and is fed — usually through a circuit breaker — into a bus. Feeders, that is feed lines to various electrical machines or distribution areas, are tapped off the bus, usually through circuit breakers. The circuit breakers serve as a disconnecting means. The switching operations may be manual or automatic. Protective relays are usually installed with circuit breakers in order to automatically disconnect the affected lines and equipment in case of a short-circuit or an overload. Instruments are usually installed in switchgear to indicate power flow in various circuits.

The system of buses, circuit breakers, protective relays, instruments, and controls, with the necessary structures, is called switchgear.

Problem— An assembly line of welders is fed from a single 450 kva transformer as shown in diagram. Sometimes when projection welders are in operation the seam welders skip a spot. Welders are single phase and are distributed on phases of a three phase source. Voltage swings when the projection welders operate reach 35 volts. Swings on 13,200 volt system are negligible.—S. L. F.



Solution— Break the bus and supply a new 150 kva transformer for the projection welders as shown.



(Series capacitors are too costly since their rating must be very high to take care of transient loading conditions existing when welders operate.)

"What's the Answer?" is conducted for the benefit of readers of ELECTRICAL REVIEW who have questions on central station, industrial or power plant equipment. Send all questions to the Editors of ELECTRICAL REVIEW.

NEW GAS TURBINE DEVELOPMENTS IN AIR, LAND, MARINE UNITS

Remarkably, in view of the present attention being accorded it, the gas turbine is not an invention of recent origin but a machine with a history that antedates the birth of Christ. The progress of the gas turbine has been retarded primarily because of a previous lack of suitable high temperature materials and efficient compressors. Now rapid advances in both of these fields during the last decade assure the gas turbine a definite place in the power sphere and account for most of its current recognition.

Various present day applications of the gas turbine, indicating the practicability of this type of equipment, have furthered its emergence from a realm of academic interest to one of reality. The gas turbine is now being actively employed in several principal ways. To date Allis-Chalmers has built 25 prime-mover type gas turbine units for oil refineries utilizing the Houdry catalytic cracking process in the manufacture of high octane gasoline. Vast numbers of high speed, light weight gas turbines are used in aircraft turbosuperchargers, and are performing commendably in this particular type of installation.

JET PROPULSION

Current press releases have publicized the adaptation of the gas turbine to the jet propulsion of airplanes. In this application a compressor is driven by a gas turbine, the latter receiving high temperature motive fluid from combustion chambers interposed between the compressor discharge and the turbine inlet. The residual kinetic energy of the gas leaving the turbine enhanced by a subsequent expansion provides the propulsive jet for propelling the plane. The fuel consumption of this type of unit in its present form in all probability precludes its general use for other than military aircraft, but modifications of the current type having improved thermal efficiency and also propeller-jet and reciprocating engine-gas turbine combinations will probably enjoy more diversified future applications.

Several other special experimental gas turbines have been recently constructed. Notable amongst these are a 4000 kw electric generating unit installed in a bombproof power plant in Neuchatel, Switzerland, and a 2200 hp gas turbine-electric locomotive for Swiss Federal Railways.

Other applications for both land and marine service offer attractive potentialities. The basic gas turbine cycle embodying a turbine, compressor and combustion chamber with its moderate thermal efficiency and low relative cost has an immediate use as a "peak-knocker" on electric power systems. The intermittent operation in this instance would justify this type of unit. Modifications of the basic cycle comprising intercooling, reheating, and regeneration are capable of producing thermal efficiencies comparable with those of modern steam power plants. However, before such cycles could be justified economically for general base load operation in central station practice, it will probably be necessary to resort to the use of powdered coal. The difference in cost between coal and oil offers a real incentive for the employment of solid fuel. Experiments with pulverized coal for gas turbines are promising but certain problems still have to be solved before a satisfactory coal-burning unit is obtained.

MARINE UNIT SOON

The marine application of the gas turbine for ship propulsion will probably materialize in the near future. First attempts should be undertaken with merchant vessels as their essentially constant load characteristics, as compared with the extremely variable power requirements of combatant ships, ideally suit them to the gas turbine. The problem of astern operation with gear drive is more acute in the case of the gas turbine since, unlike the steam turbine, it normally exhausts at atmospheric pressure thereby requiring a separate vacuum system to provide a low density atmosphere in which to rotate the astern and ahead turbines during forward and reverse operation, respectively, so as to prevent prohibitive windage losses. The reversing problem could be mitigated by the use of electric drive or a variable pitch propeller, thus eliminating the necessity of providing a separate astern turbine.

GAS TURBINE - - READY FOR RAILS

Natural advantages of this prime mover and latest advances in gas turbine development promise success of new design for 90-foot locomotive.

J. T. Rettaliata

MGR., RESEARCH AND GAS TURBINE DEVELOPMENT • ALLIS-CHALMERS MANUFACTURING CO.

● An up-to-the-minute review of potential applications emphasizes the versatility of the gas turbine, but one of the most promising applications on which engineering is already well along is currently the gas turbine locomotive drive. When considering the selection of power plants for locomotives, the combustion gas turbine appears to have certain natural advantages of sufficient import to justify its adoption for such service.

One condition alone — the fact that no water is required in the gas turbine cycle — makes this promising type of power plant particularly attractive for locomotive installations. Elimination of the now necessary water treating provisions and frequent inspections, cleanings, and repairs of boilers used on present steam locomotives should certainly be desirable. Of additional importance would be the improved operating schedules possible on runs which formerly made stops for water.

The large amount of excess air used in the gas turbine combustion process permits a clear stack completely free from smoke at all loads on the unit, a feature which would certainly simplify the present problem of complying with city ordinances.

The purely rotary motion of the gas turbine will result in minimum maintenance and vibration. Absence of any reciprocation, with its accompanying unbalanced forces, is obviously beneficial. Since the elements of the gas turbine are similar to those of steam turbines, maintenance after development should be essentially moderate, except for any additional which may result from higher temperatures employed. Operating experience with the Houdry turbines indicates very low maintenance for this equipment, which works at temperatures in the range of those employed in modern high temperature central station practice. Continuous operation for as long as two years without shutdown — the record of several of the oil refinery gas turbines — indicates their exceptionally high reliability.

Because there are no sliding surfaces except for journal bearings, lubrication costs of the gas turbine should not exceed one percent of the fuel costs, substantially less than such costs on present railway equipment.

Consider burning oil or coal

It would undoubtedly be desirable to have a coal-burning gas turbine locomotive, but utilization of coal for fuel must await the results of promising experiments now being conducted with pulverized coal. The inherent low heat release of coal, necessitating combustion chamber volumes which are relatively large when compared with liquid fuel, limits its consideration at present to stationary plants where space and weight are not at a premium as in mobile installations. Therefore, until higher heat release apparatus is developed, it appears that liquid fuel will be used in locomotive applications. Colloidal fuels should also be given consideration, but in their present state high preparation costs lessen their attractiveness somewhat.

When dynamic braking is considered, the advantage of applying the gas turbine to locomotives is readily apparent. By operating the traction motors as generators the motorized main generators may be loaded by driving the gas turbine and its associated compressor. The energy required during compression can be dissipated by discharging the compressed air to atmosphere. With such an arrangement the electrical resistor grids normally required for dynamic braking are eliminated.

The thermal efficiency of the gas turbine naturally will vary with the type of cycle employed. For locomotive service, where space limitations will have an important influence, certain refinements permissible in stationary plants will necessarily have to be omitted. Assuming a turbine inlet temperature of 1200 F, the simplified basic cycle comprising a compressor, a turbine (or two turbines arranged in parallel), and a combustion chamber will yield a thermal efficiency at the shaft coupling of about 19 percent. If a more elaborate cycle of the reheat type, employing a mod-

Material in the above article was delivered as a paper before the annual meeting of the American Society of Mechanical Engineers in November, 1944.

AT LEFT: One of the 25 Allis-Chalmers gas turbines now performing successfully in oil refinery service, this 40,000 cfm unit is one of two generating 10,255 hp in a 100-octane gasoline plant in Ohio.

erate amount of regeneration and operating with turbine inlet temperatures of 1200 F is adopted, thermal efficiencies of 25 percent are possible. With a hydro-mechanical type of transmission of 90 percent efficiency, these thermal efficiencies when referred to the rail would become 17.1 and 22.5 percent, respectively. With an electrical transmission having an efficiency of 83 percent, the respective rail thermal efficiencies would be 15.8 and 20.8 percent. Considering the low grade fuel oil which it is capable of using, these efficiencies make the gas turbine drive appear attractive when compared with other types of locomotives on a fuel cost basis.

In 1939 Allis-Chalmers conducted an engineering study of the combustion gas turbine as a locomotive drive. Consideration was given to four different gas turbine locomotives, including (a) a 5,000 hp unit with hydro-mechanical transmission driven by two separate power turbines each connected to a main gas turbine-axial compressor set; (b) a 5,000 hp unit with hydro-mechanical transmission driven directly by two main gas turbine-axial compressor sets; (c) a 4,500 hp unit with electrical transmission driven directly by two main gas turbine-axial compressor-electric generator sets; and (d) a 2,250 hp unit with electrical transmission driven directly by a single main gas turbine-axial compressor-electric generator set. A heat exchanger was also incorporated in the latter design.

Electric drive selected

The results of this study led to the conclusion that the hydro-mechanical transmission, comprising reduction gear, torque converter and hydraulic coupling, essentially duplicated the favorable performance characteristics of the electrical transmission and, in addition, had weight and efficiency advantages which made it the most promising type of drive. Notwithstanding this decision, which is still believed to be justified and valid in every respect, the locomotive design considered here involves an electric drive.

The selection of the latter type of drive was not due to any inadequacies in the mechanical transmission, but rather to the fact that much operating experience has been acquired with the electrical type, so that advantage could be taken of its well known characteristics, permitting more intensified concentration on the development of the gas turbine itself. Furthermore, adoption of the electrical transmission appeared to be the most judicious procedure at this stage, since certain established maintenance facilities could still be used. Also, the railroad personnel, being familiar with it, would be required to learn only that additional operating technique pertaining to the gas turbine equipment. After the gas turbine has been proven to be a reliable and desirable type of railroad motive power unit, it is believed that further developments should include the mechanical transmission in order to achieve the ultimate in locomotive design.

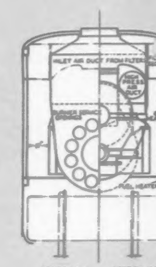
Proposed gas turbine locomotive

The proposed road locomotive (Fig. 1) is of 4,800 hp capacity, being powered by two duplicate 2,400 hp gas turbines each driving, through a reduction gear, direct-current main and auxiliary electric generators. The main generator is connected to traction motors furnishing power to the axles.

Overall length of the locomotive is 90 ft and the distance between bolster centers is 58 ft 4 in. The two 3-axle trucks with 16 ft wheel base have 52 in. diameter driving wheels, and each axle is powered by a nose-hung direct-current traction motor. When compared with conventional steam locomotive wheel arrangements, the 2-truck design with provisions for proper lateral axle motion and the elimination of the reciprocating motion of pistons and side rods can be expected to reduce track maintenance.

The estimated weight of the locomotive is 450,000 lb, with possibilities of reduction by employing light weight materials. This is approximately one-half the weight of some other types of modern locomotives

Fig. 1 — An electric drive is used for the 4,800 hp gas locomotive proposed in the accompanying article, primarily because most operating experience has been acquired with this type. The unit is so compact it is contained in a single cab 90 feet long. Its weight is estimated to be 450,000 pounds, about one-half the weight of other types of modern locomotives of the same horsepower.



of corresponding horsepower. The wheel loading per inch of diameter does not exceed accepted present practice. The two 2,400 hp gas turbine power units are arranged with one at each end of the locomotive cab, permitting the weight to be more uniformly distributed, with most of it directly over the trucks. For each power unit the common frame carrying the turbine, compressor, reduction gear and generators is supported at three points for the purpose of maintaining correct alignment. Two of the support points are located laterally directly over the center axle of each truck, while the third, in vertical line with the No. 1 turbine bearing, is on the centerline and near the center of the cab.

The filters for the intake air to the gas turbine-compressor units are located on both sides of the cab near the top at each end. They are placed as high

as feasible so as to reduce the possibility of inducting disturbed foreign objects along the roadbed. Furthermore, the high intakes are desirable when the locomotive is standing in a station with engines running, where passengers may be in the vicinity.

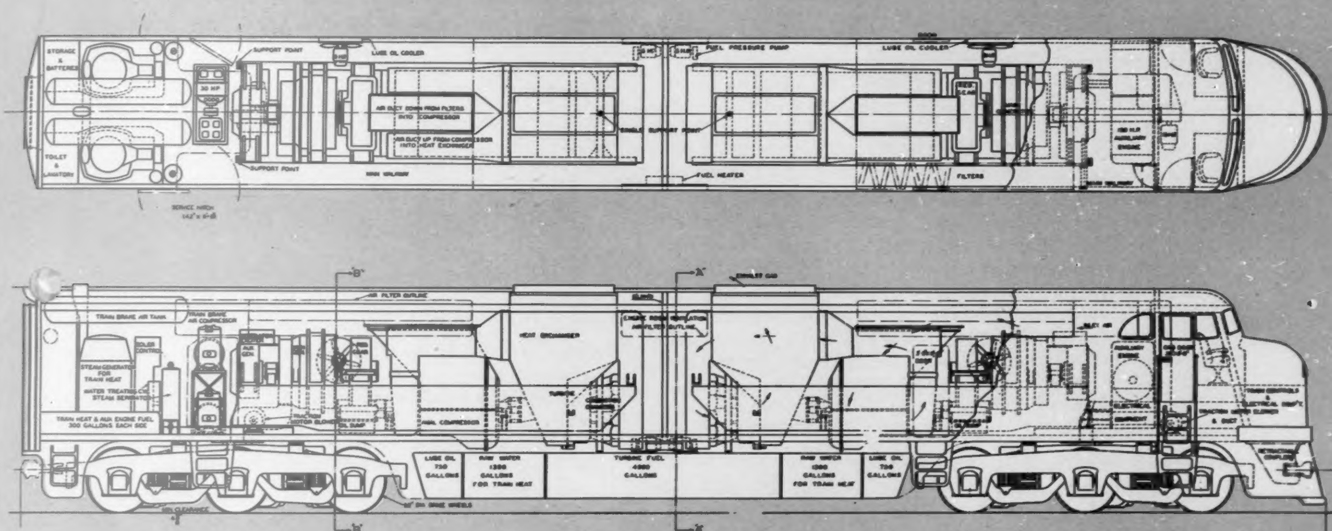
The exhaust gases leaving the heat exchangers are discharged through the roof of the locomotive.

Two 2,250 lb per hr steam generators are provided for train heating. It is possible, with the gas turbine type of drive, to install a waste heat boiler in the exhaust passage beyond the heat exchanger and generate steam for heating purposes. However, for simplicity only the conventional type of boiler is indicated. After a sufficient accumulation of operating experience has proven the merit of the gas turbine itself, it would probably be expedient to incorporate in future locomotive designs a waste heat means of generating heating steam also. For trains employing electric instead of steam heating, as is found primarily in European practice, the gas turbine is singularly adaptable, since its output increases essentially linearly with decrease in atmospheric temperature. However, direct firing of the fuel under a boiler is actually a much more efficient method for producing an equivalent amount of train heating.

An auxiliary engine-generator set of 150 hp is provided for starting the two gas turbine power plants by motorizing the main generators. One of the numerous advantages of having two smaller power units instead of a single larger one of the same aggregate output is apparent in this instance since it permits smaller-capacity starting equipment to be employed. By connecting the auxiliary set directly to the traction motors it may also be used for propelling the locomotive up to speeds of approximately 15 mph, enabling the main units to be kept shut down when moving the locomotive about the yards.

Since the use of a relatively heavy low grade fuel is contemplated, provision is made for fuel heating. There are various methods of accomplishing this, either with steam or electrical heating, but probably the most logical would be to use the exhaust gas from the turbines. For starting purposes the light auxiliary engine fuel, requiring no preheating, could be used temporarily in the combustion chambers of a main power unit until the flow of exhaust gas is established.

Tank capacity for 4,000 gallons of turbine fuel oil, 1,500 gallons of lubricating oil, and 2,600 gallons of water for train heating is provided in the space under the center of the cab between the two trucks. The fuel oil capacity is sufficient for approximately a 10-hour run. Two 300-gallon tanks in the rear of the cab contain fuel for the auxiliary engine and the steam generators.



No water is required for the gas turbine power plants themselves as all cooling is done with air. Two fan coolers are used for the lubricating oil, and blowers for cooling the generators and traction motors.

Train controls and associated electrical equipment are in the forward end of the locomotive.

After development is completed it is estimated that the expected cost of the locomotive will be approximately $75 to $85 per horsepower.

Gas turbine power plant

In the operation of this power plant (Fig. 2), a five-stage reaction type gas turbine (A) drives a 22-stage

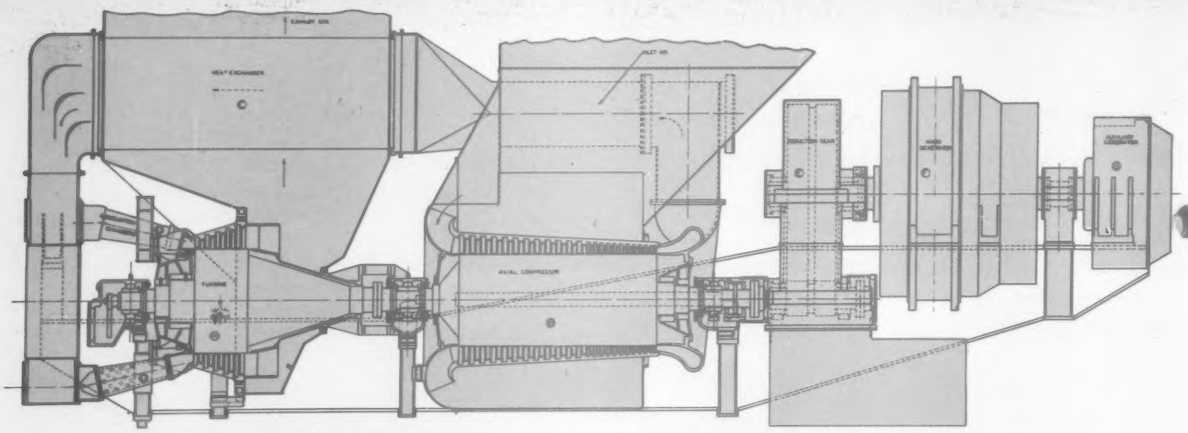


Fig. 2 — Locomotive is powered by two of these 2,400 hp gas turbine power plants.

axial compressor (B). Filtered air from the atmosphere traverses the compressor where its pressure is increased. It next passes through the cross-flow heat exchanger (C), where its temperature is raised by the turbine exhaust gas. The heated air then flows in parallel through a group of twelve separate combustion chambers (D) ahead of the turbine. Part of the air is used for combustion purposes in an inner shell, the balance flowing through the annular space between the inner and outer shells and cooling the products of combustion to a satisfactory turbine inlet temperature. A series of smaller combustion chambers is used instead of a single large one, as it has been found that in certain instances more satisfactory combustion at higher heat release can be obtained in this manner. The gas, a mixture of air and combustion products, then expands through the turbine from which it is exhausted to the atmosphere through the heat exchanger, where it preheats the air from the compressor. The power developed by the turbine is greater than that required by the compressor and the excess power is supplied through the reduction gear (E) to the main generator (F) and the auxiliary generator (G).

In order to start the unit from a standstill the generator is switched from shunt to series field and motorized by the auxiliary engine-generator set, bringing the unit up to about 30 percent of maximum operating speed, at which point the turbine, at full gas temperature, is capable of driving the unit by itself. The full load speed of the turbine and compressor is 5,000 rpm and that of the generators is 900 rpm. The turbine and compressor, supported on a common frame with the gear and generators, are arranged as a three-bearing unit.

The gas turbine is designed for a maximum continuous operating temperature of 1200 F. The thermal efficiency of a gas turbine cycle improves with increase in turbine inlet gas temperature, so that it is desirable to use the highest temperature consistent with mechanical reliability. In the present state of gas turbine development it is believed that 1200 F is the maximum temperature which should be adopted for prime mover type of power plants where continuous operation with reliability is a basic requirement. It is true that certain aircraft gas turbine applications are designed for higher temperatures, but this can be justified in such instances where the low atmospheric temperatures associated with high altitudes afford ideal cooling means and where limited service life is acceptable.

The proposed locomotive gas turbine element is in general similar to that of Fig. 3, which shows one of the turbines used in the Houdry oil refinery units. Its associated axial compressor, shown in Fig. 4, is also of the type employed in the locomotive unit. Thus the basic turbine and compressor designs resemble very closely those which have performed so reliably in oil refinery service.

The cross-flow, tubular type heat exchanger, which has an effectiveness of 50 percent, has a surface of 1.4 sq ft per useful horsepower output of the gas turbine power plant.

A discussion of the characteristics of the gas turbine locomotive will conclude this article in the March Allis-Chalmers Electrical Review.

Fig. 3 — Gas turbine element of the locomotive will be similar to this one used in the Houdry oil refinery gas turbine units.

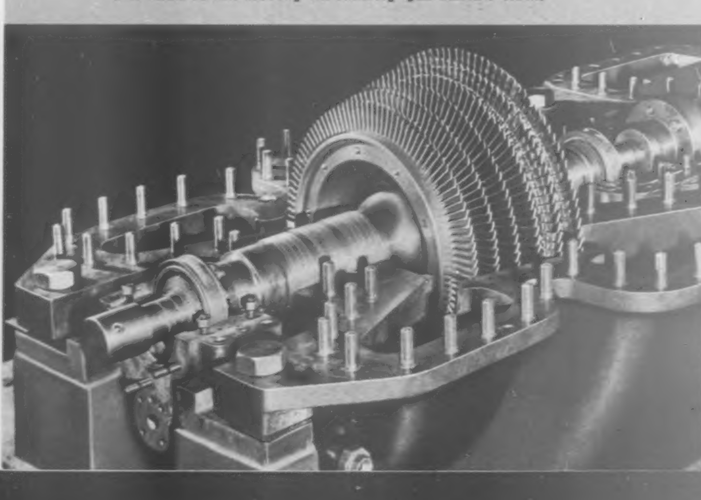
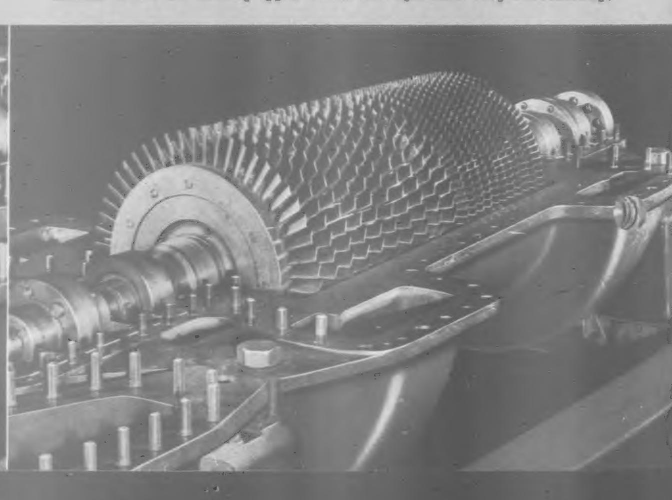


Fig. 4 — Axial compressor of locomotive power plant will also be similar to the oil refinery type, which has operated very successfully.



HOW TO SELECT STORAGE BATTERIES FOR SWITCHGEAR

Set rules enable industrial and utility users of switchgear to choose the most satisfactory batteries for control and breaker operation. Knowledge of loads and battery characteristics are "musts" in selection.

Robert Loewe

SWITCHGEAR SECTION • ALLIS-CHALMERS MANUFACTURING COMPANY

In planning a switchgear installation there is often little serious thought given to the selection of a storage battery. As a result, the battery may be too small . . . unable to provide sufficient power for more than a few breaker operations during a short interval. On the other hand, if it is too large, the battery may unnecessarily tie up a large financial investment. Actually, more careful selection of this very important accessory in any power plant or station may easily pay big dividends, both from a financial standpoint and that of adequacy of service.

Selection of a suitable battery is not a difficult process since there are definite rules that serve as guide posts for the utility and industrial users of switchgear to aid their selection of the most satisfactory batteries for control and breaker operation. Among the important factors to be considered are these:

1. Type and magnitude of load
2. Limit of usable voltage
3. Ambient temperature
4. Charging facilities
5. Reliability of maintenance
6. Space requirements

Load Classifications

Loads on station storage batteries fall into three general classifications — steady, intermittent, and emergency.

Steady loads will consist, in most cases, of switchboard indicating lamps which are generally small and will draw about 40 milliamperes each. Attention must also be given to the indicating lamp circuits to determine the maximum number of indicating lamps that will be on at any one time. As a rule each circuit breaker has two indicating lamps, one indicating the open position, the other the closed position of the breaker. Only one of these will be lit at any one time, and must be so considered in figuring the load. In some instances, there are also indicating or pilot lamps for other purposes, such as to indicate potential on the control circuit, the position of certain other auxiliary equipment, or for annunciator indication. It is also not unusual to have certain contactors which will be energized for a large portion of the normal operating time, and these should be considered when the steady load requirements on the storage battery are being estimated. Their values can easily be determined by consulting the manufacturers of the particular devices in question.

The intermittent loads are generally those of tripping and closing circuit breakers, but also include certain other devices like electrically operated valves, motor operated rheostats, alarm devices, governor motors, and field switches. The demands of field switches are similar in effect to those of circuit breakers inasmuch as they generally consist of a circuit breaker that has been modified for this service by the application of field discharge contacts. In each case consultation of the manufacturer or his descriptive literature will determine the magnitude of this type of load.

The emergency load consists usually of a certain portion of the station lighting service. The value of this can usually be determined by counting the number of bulbs of each size on the emergency lighting system and arriving at the total load in amperes. Usually this must be considered also in relation to the maximum time that the station will be without normal lighting service in the case of such an emergency. In an attended substation this is usually considered to be about three hours. In unattended stations it may be as long as twelve hours. The length of time that the emergency load would be carried by the station storage battery is determined by the individual circumstances and the location of the station.

Usable voltage limit

Circuit breakers are generally required to close and

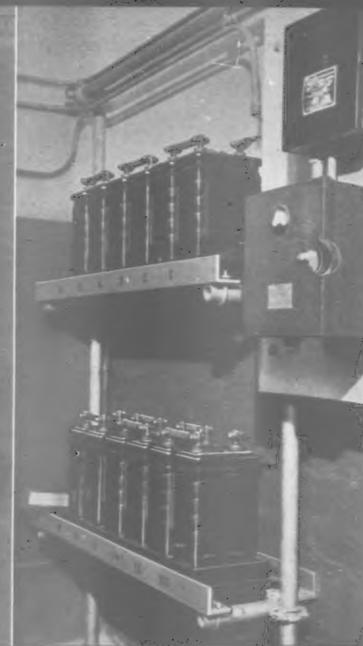


Fig. 1 — Large central station storage battery used for closing, tripping, and control service of the kind described below.

Fig. 2 — A 24-volt battery of the type which is generally used in unattended stations for tripping service.

trip over a given specified range of voltage. For direct-current these are as follows:

Nominal Closing Voltage	Range of Closing Voltage
48	36-52
125	90-130
250	180-260

The standard range of voltages for tripping on direct-current are as in the following table:

Nominal Voltage	Voltage Range
12	7-15
24	14-30
48	28-60
125	70-140
250	140-280

These are voltages measured at the coil terminals of the breaker in question. Due to the voltage drop that will occur in the leads from the battery to the breaker, it is wise to figure on a minimum voltage of about 1.75 volts per cell at the storage battery. In the case of a 125 volt, 60 cell battery, this will give a total voltage of about 105 volts minimum. Similar minimum battery voltages using the same value of 1.75 volts per cell can be figured for other batteries in the same manner.

A maximum voltage corresponding to about 2.15 volts per cell should similarly be used. At this figure there will be no undue shortening of the life of the indicating lamps.

Ambient temperatures

In most indoor locations little regard need be given to the subject of ambient temperatures and its effect on the discharge rate of the storage battery. Ratings are generally given at a standard temperature of 77 F. When ambient temperatures are likely to be very much less than this, the published ratings should be corrected. These derating factors vary from one manufacturer to the next. In one case, for example, the one minute discharge rate is reduced about 0.9 per cent for each degree F below 77 F and at the 12 hour rate this becomes 0.7 per cent. At higher temperatures the rating may be increased, but this is not generally considered in the application of storage batteries.

In some cases operators will always be present to provide close supervision of the battery charging rates and voltage and to provide other attentions such as adding water and electrolyte where and when it is necessary. With the pasted plate batteries and their shorter life expectancy, a sufficiently greater amount of maintenance care should assure satisfactory performance. When the station is unattended the more expensive planté type will generally be the better selection and is the one recommended.

Capacity and space requirements

Each cell is made up of a number of positive and negative plates. The number of these plates is always odd as there is one more negative than positive. A 17 plate battery would consist of 8 positive plates and 9 negative plates per cell.

Each of the three types of load is considered separately, and the battery capacity required for each is the sum of the three requirements. The number of positive plates necessary for the steady loads is figured on a discharge rate of 1.75 volts per cell for 12 hours, the intermittent load on a discharge rate of 1.75 volts per cell for 1 minute and the emergency load on a discharge rate of 1.75 volts per cell for 3 hours. Other periods of time may be considered in particular cases.

The storage battery manufacturers' literature will give these rates either in the form of curves or tables. In addition, for each particular type of battery they manufacture they will give the range of total number of plates per cell that may be obtained. The minimum is generally either 3 or 5 plates. This would mean a minimum of one or two positive plates per cell.

In indoor applications of station storage batteries, it was formerly always considered necessary to have a separate room. With modern methods of charging and charge control, the amount of gas and acid given off by the batteries is usually so small that separate housing is no longer necessary and the battery may be located as close to the switchgear as is desired.

In outdoor switchgear the battery and its charger are generally mounted in some unused portion of one of the auxiliary units. Figure 2 shows a battery of this type and Figure 3 shows the location. This is true only if the battery is constructed to eliminate the possibility of emitting excessive corrosive vapors.

Typical battery selections

1. An attended indoor station has normal operating temperatures and contains 10 circuit breakers. These breakers require 4 amperes to trip and 80 amperes to close at 125 volts. There will be a maximum of 13 indicating lamps each taking 0.04 amperes. There are no other steady loads. The emergency load will be about 5 amperes and have a maximum duration of 3 hours. Consider one breaker closing or two breakers tripping at any one time.

For this application, since it is an attended station and not a very large one, a pasted plate battery would be recommended. Assume one which has cells available with 5 or 7 plates and discharge rates as follows:

One minute rate is 70 amperes per positive plate.
Three hour rate is 10 amperes per positive plate.
Twelve hour rate is 4 amperes per positive plate.

The 13 indicating lamps will require a total load of 0.52 amperes. This figure divided by 4, which is the 12 hour discharge rate, gives $\frac{.52}{4}$ or 0.13 positive plates as the requirement for the indicating lamps. The 5 ampere emergency load would require 5 divided by 10, or 0.5 positive plates.

For the circuit breaker load, figure separately the tripping and closing requirements and take whichever one of these is the greatest. In this example there is a maximum of two breakers tripping at any one time. Therefore, two times four, divided by 70, will call for 0.12 positive plates. For closing, 80 divided by 70, or 1.14 positive plates are required. Here, obviously, the closing load is greater than the tripping, and the closing load is the one to be used. The total number of positive plates is then found by adding the 3 requirements for the different loads, which in this case equals 1.77. Always take the next full number of plates, in this case 2. The total number of plates per cell is then 2 positive plus 3 negative or a total of 5.

2. Consider an attended station where the temperatures are normal and 22 circuit breakers each requiring 4 amperes per trip and 60 amperes to close at 250 volts. There will be a maximum of 28 indicating lamps of the same size as in example No. 1. Other devices will furnish a 2 ampere steady load. The emergency load will be 2 kw and will be in demand for a maximum period of 3 hours. Two breakers in this station may close simultaneously or 3 may trip simultaneously. Again we will assume a pasted plate battery of the same characteristics as in the first example. In this case the steady load from the indicating lamps is 1.12 amperes. Added to this is the other steady load of 2 amperes, which gives a steady load requirement of 3.12 amperes. This will require 0.8 plates (3.12 divided by 4). The emergency load in this case is 8 amperes, so that 0.8 plates is the requirement.

For tripping there is a total maximum current of 12 amperes. This divided by 70 will give 0.18 plates. For closing we have a maximum demand of 120 amperes. This divided by 70 will give 1.8 plates which again is larger than that required for tripping. The total requirements found by adding the three types of load will give 3.4 as the sum. As a result, use 4 positive plates per cell, or a total number of plates in each cell of 9.

In this example if the station had been unattended and in a rather cold location the derating factors for ambient temperature would have to be applied.

Conclusion

These examples illustrate the ease and simplicity of the method. A battery chosen too small is useless, and one too large represents money wasted. With this method it is necessary to know only the loads and the battery characteristics as given by the battery manufacturer to make a correct selection quickly and easily.

ON FOLLOWING PAGES — Grand Coulee Dam develops 1,300,000 horsepower for the west coast, will eventually produce over 3 million. To meet emergency power needs, two huge Allis-Chalmers hydraulic turbines designed for California's Shasta power plant were successfully adapted to Grand Coulee design and now operate at efficiency of over 92 percent. — Robert Yarnall Richie photo.

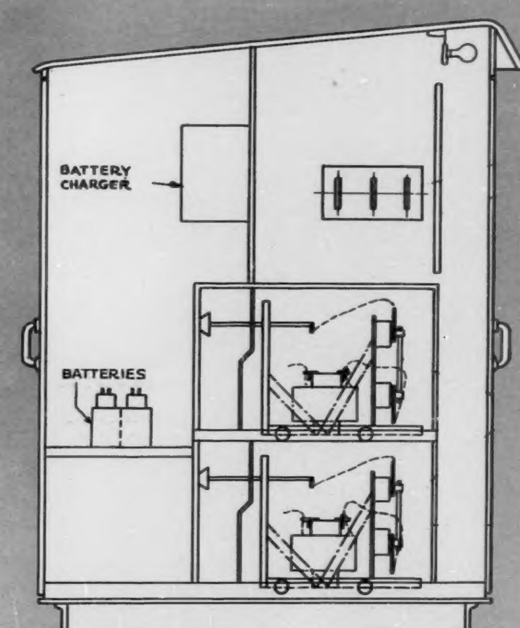


Fig. 3 — This switchgear diagram shows the method of installing tripping battery and charger in auxiliary unit of an outdoor unit substation.

REACTIVE POWER CONTROL—ANOTHER REGULATOR JOB

Besides their regular job of compensating for voltage drop or correcting source voltages, regulating transformers can solve reactive power and voltage problems on parallel feeders, tie lines, and loop transmission lines.

W. L. Peterson

TRANSFORMER SECTION • ALLIS-CHALMERS MANUFACTURING COMPANY

● Compensating for voltage drop or correcting a fluctuating source voltage are the problems generally assigned to feeder voltage regulators, regulating transformers and transformers with load-ratio-control. In avoiding the necessity of wrapping additional copper or replacing existing lines with heavier copper, they are unquestionably successful from economic and engineering standpoints in these applications to radial feeders.

But the use of regulating equipment on radial feeders is not its only use — it can solve problems of reactive power flow along with voltage problems. And savings as important as those obtained on radial feeders are possible.

Regulating equipment is often used in the solution of reactive power flow and voltage problems on:

1. Parallel feeders.
2. Tie lines.
3. Loop transmission lines.

In these applications of parallel circuits, the following general rules must be remembered:

1. In-phase voltage regulation controls reactive kva flow.
2. Quadrature voltage regulation controls kw flow.
3. To raise the voltage of a line or section of a line, such as a loop, the voltage supplied to the line by all generators and all load-ratio-control transformers must be raised, or the only effect is to circulate reactive kva.

Each application must be engineered thoroughly with special consideration being given to the problem of reactive power flow. In analyzing any problem involving reactive power flow, it is often helpful to consider the transformer regulating equipment and its source as a generator with field control. Operation of regulating equipment to raise or lower the voltage has the same results as regulating the voltage from field control on the source generator. In this study, it might be well to consider several installations that have proven themselves with actual operating records.

Parallel feeders

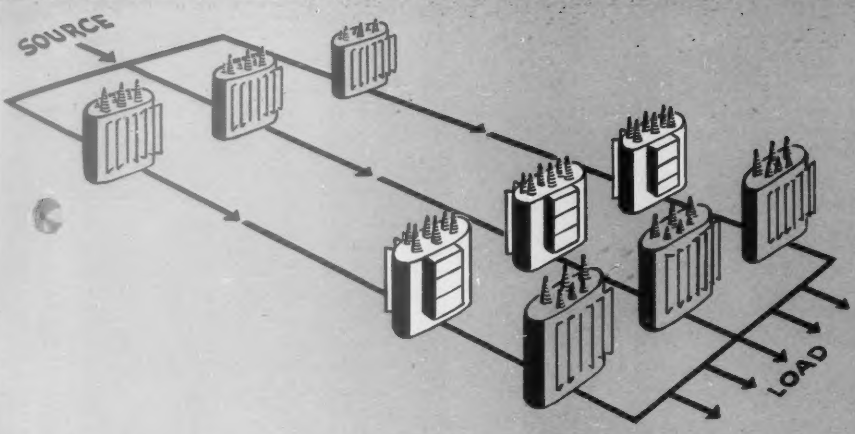
The use of regulating transformers on paralleling feeders is a very common application. In one particular application, Fig. 1, a common source with three paralleling lines feeds a common bus. The paralleling lines do not have the same resistance and reactance characteristics, as they were built under priority restrictions and different size copper was used in each line.

The problem was to correct for variable source voltage and line drop in the paralleling lines and to hold constant voltage on the load bus at all loads. Also, it was desirable to balance the kva load in each line so that the transformers would be equally loaded.

The solution to the problem was the installation of a regulating transformer in each line. The regulating equipment with automatic voltage control was provided with paralleling means to keep the output voltages equal and thus prevent circulating currents. Negative reactance compensation was used as it is the simplest and allows the regulating equipment to regulate independently to maintain balanced current in the lines.* In other words, a paralleling scheme which would hold the regulators in exact step with each other would not correct for the difference in the line characteristics. With the equipment installed, the voltage was maintained at less than one percent variation from nominal voltage and the paralleling lines were equally loaded.

The installation of three regulating transformers operating in parallel presents the same problem as operating three generators in parallel on a common drive shaft with individual field control on each gen-

*Allis-Chalmers Electrical Review, March 1943. "How to Parallel Regulators to Increase Feeder Capacity." W. L. Peterson and R. P. Marohn.



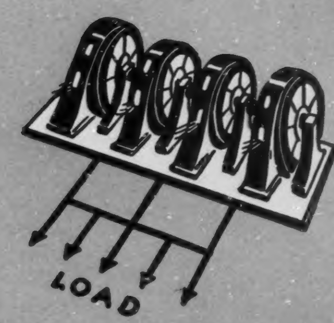
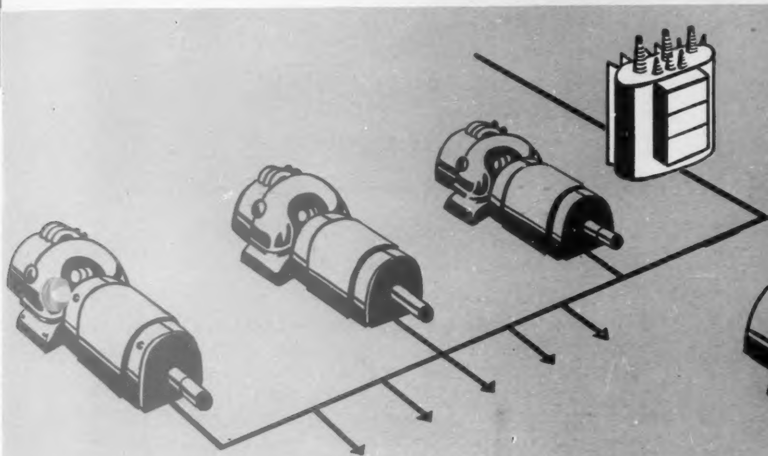


Fig. 1 — A common source with three paralleling lines feeds a common bus, a regulating transformer is installed on each line.

Fig. 2 — The three regulating transformers operating in parallel is compared with three generators in parallel on a common drive shaft.



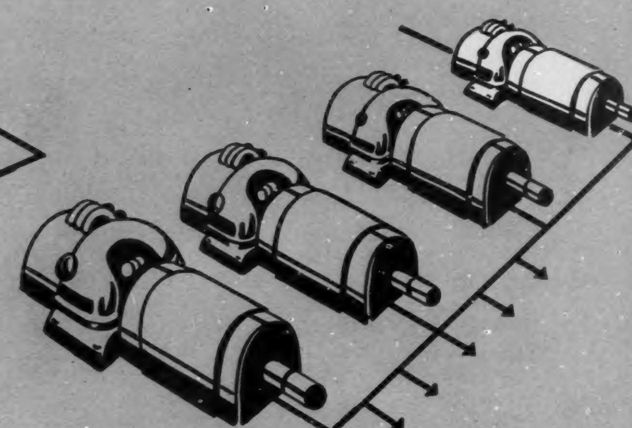
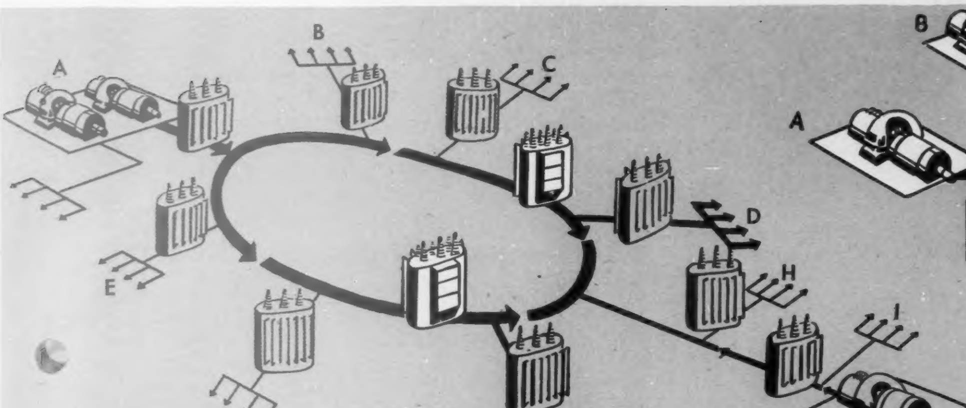


Fig. 3 — A step-down transformer with load-ratio-control installed on tie line of a large public utility system.

Fig. 4 — Installing a tie line and transformer (Fig. 3) is analogous to the additional generator in the arrangement above.



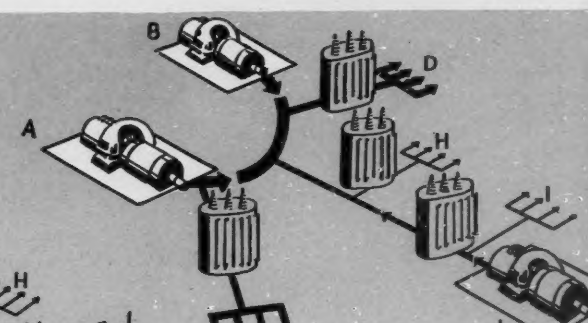


Fig. 5 — There are two feeder voltage regulators operating in parallel in the loop transmission line illustrated in the sketch above.

Fig. 6 — Generators operating in parallel are similar to the regulators operating in parallel in the drawing at the left, Fig. 5.

Fig. 7 — A 25,000 kva regulating transformer being prepared for shipment to a Midwest utility for installation on a tie line.

erator (Fig. 2). If the field on one generator is increased it will increase its reactive load, and if the field is decreased it will decrease its reactive load. If the field on each generator is increased a corresponding amount, the output voltage of the system is increased. This is also true with the regulating transformers. In order to increase the voltage of the system, the turn ratio must be changed simultaneously and in the same direction in each of the three units. Therefore, the tap changing mechanisms must operate together, or in parallel.

Tie lines

In this installation, a small generating plant did not have sufficient capacity to furnish growing war plant loads. The plant was having difficulty with highly fluctuating loads from arc furnaces, low voltage, and poor frequency control. It was decided that the best solution to the problem was a tie to the neighboring public utility system, as shown in Fig. 3. At the point of the tie, the utility could not maintain constant voltage because of the war limitations on the equipment needed.

The problem resolved itself into providing additional capacity to the generating plant with least amount of reactive power flow from the tie line.

The solution was the installation of a step-down transformer provided with load-ratio-control and automatic voltage control of the regulating equipment. Negative reactance compensation was provided on the automatic voltage control to limit the reactive power flow from the tie line.

The installation of the tie line with a regulating transformer resulted in increased capacity of the generating plant, with the tie line taking the load swings. The generators in the generating plant handled the base kilowatt load and furnished the necessary reactive power. The voltage of the system improved and the frequency was maintained at that of the utility system.

Again an analogy can be drawn to the problem of operating generators in parallel with automatic field control on the generators. Installing the tie line and transformer with automatic load-ratio-control is similar to installing an additional generator, as shown in Fig. 4. The voltage control of the transformer acts like the field control of the generator — change in the exciting field of the generator is the same as a change in the transformer turn ratio. An increase in the exciting field current of the generator would result in increased reactive power load. Likewise, an increase in the output voltage of the transformer results in increased reactive power flow from the tie line. To raise the voltage of the system, the output voltage of the transformer and generators must be raised together.

Loop transmission lines

One feeder voltage regulator installation which has been in service for some time (shown in Fig. 5) consists of two regulators operating in a loop which makes up a tie line. The system consists of a sizable generating station at A which delivers power to the various loads indicated. A station of smaller generating capacity at J furnishes some power into the tie line in the normal direction of load flow indicated.

The main problem was the low voltage at loads D, G. H, and I. The generator at J could not raise the voltage at its end of the system, as an increase in field excitation resulted in a shift of reactive kva being furnished the system from generator A to generator J with very little increase in voltage at J. Generator J did not have sufficient capacity to furnish the additional reactive kva, and station A had to be relied upon to furnish the reactive load. Changing the transformer taps in the high line at J of course would have the same result as increasing the voltage on generator J.

There were several possible solutions to the problem. The line could be rebuilt with heavier copper, additional generator capacity could be installed in the area of low voltage, or feeder voltage regulators could be used. The most economical and practical solution was the installation of feeder voltage regulators with automatic voltage control at D and G, as shown. The regulators were provided with negative reactance compensation for the parallel operation of the units. With the negative reactance compensation the automatic control was set to divide the reactive load between the two halves of the loop in the desired proportion.

As the regulators operated to increase the voltage, the generator at J could increase simultaneously its output voltage without increasing its reactive component of load. This, of course, resulted in better voltages at D, G, H, and I.

Placing regulators in the loop required parallel operation, for if they did not, the output voltage of the one unit might be greater than the other. This would cause reactive power to flow around the loop from the unit with greater voltage of a magnitude that would balance the voltage. As an analogy, the parallel operation of generators in Fig. 6 may be considered. Since the regulators have only turn ratio control to obtain the change in voltage, only the field control of the generators should be considered for the analogy. If generator A increases its field excitation it will increase its reactive kva load. If the increase is appreciable, it may cause generators B and J to operate with leading power factor. This would be the same as regulators causing reactive kva to flow around the loop.

Conclusions

It follows that the problem involved in operating regulators in parallel is not greatly different from operating generators in parallel. It should be remembered that if the regulators have only voltage control they cannot control active power flow. To obtain active power flow control a phase shift must be built into the regulator.

The same engineering and economic considerations involved in the solution of problems on radial feeders come into the picture for parallel feeders, tie lines, and loop transmission lines, where the additional problem of reactive power flow is involved. Reactive power flow problems can be solved easily if it will be remembered that in-phase voltage regulation controls reactive kva flow, quadrature voltage regulation controls kw flow, and all source voltages supplying a section of a line must be raised to raise the voltage of that section of the line.

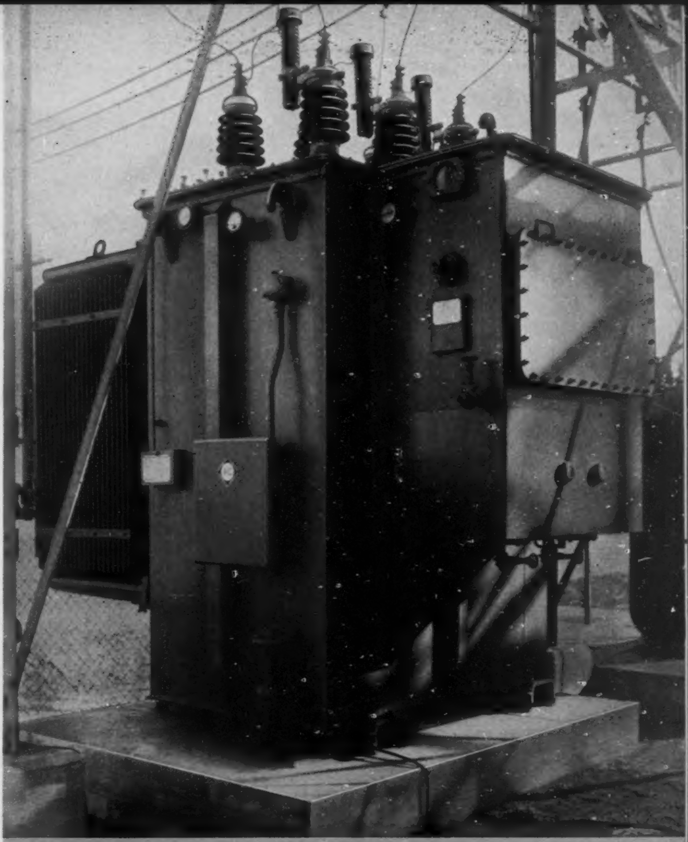
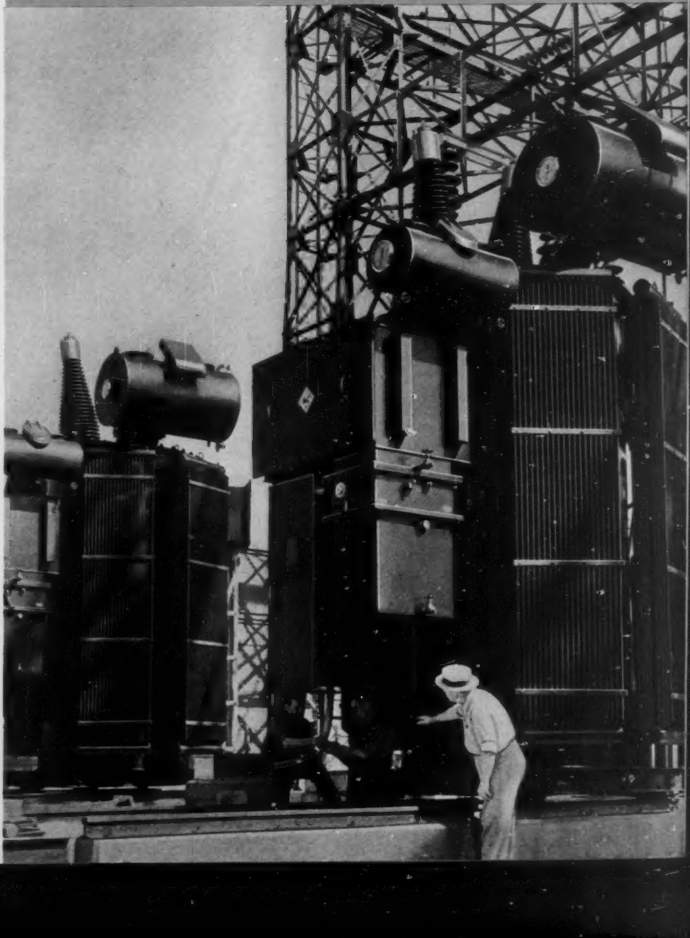


Fig. 8 — This feeder voltage regulator operates in the substation of a southwest utility.

Fig. 9 — Installing a 3,000 kva, single phase transformer with load-ratio control in a 132 kv substation.



FUNDAMENTAL PROBLEMS OF A-C CIRCUIT INTERRUPTION

Many variables and intangibles, both in the circuit and in the interrupter, make the achievement of satisfactory a-c circuit interruption an art rather than an exact science. Here are the fundamental problems and basic solutions.

Dr. Erwin Salzer

CONSULTING ENGINEER, SWITCHGEAR SECTION • ALLIS-CHALMERS MANUFACTURING COMPANY

● While the design of circuit interrupters is largely an art based on experience and empirical data, scientific research and the application of scientific principles are now assuming a predominant position in the art. Some of the more significant contributions which science has already made in the development of commercially acceptable circuit interrupters are of particular interest now and can be discussed satisfactorily in a relatively brief outline of the subject.

I—ARC INITIATION

The electrical resistance between a pair of cooperating contacts which are in engagement depends, among other factors, upon the amount of contact pressure. The contact resistance increases in proportion to a decrease of contact pressure. A decrease of contact pressure is evidently a necessary step preceding any disengagement of such a pair of contacts. At the instant of contact separation, the pressure at the last point of contact is zero, and the contact resistance correspondingly high. This causes an intense local heating at the last point of contact, even though high speed contact separation is effected which results in a very short heating period. This heating effect might also be explained in terms of current density. Separation of the contacts causes a concentration of current flow at the last point of contact existing before actual separation. As shown in Fig. 1, this concentration of current continues after contact separation and causes heating of the contacts, resulting in thermionic emission. An arc discharge is therefore initiated if the voltage across the gap between the contacts is sufficiently high.

The high temperature produced at the last point of contact causes the contact metal to vaporize; the amount depending upon the particular metal of which the contacts are made. Such metal vapors are good electrical conductors and constitute a conductive path across the gap between the contacts.

AT LEFT: In the substation of one of the big west coast electric power systems is a 150,000 kva bank of 220 kv auto-transformers forced oil-cooled with electro-coolers, also used on another 100,000 bank in the same station. — Robert Yarnall Richie photo.

Immediately following contact separation, the electric field prevailing at the gap between the contacts may be high. This condition always exists in high-voltage circuit breakers. The primary electrons which are emitted from the hot spot at the last point of contact, as well as the secondary electrons which are generated by collision between primary electrons and neutral atoms, move at high speed, under the action of the high electric field, in the direction from the contact forming the cathode to the contact forming the anode. The positive ions, produced by collision between electrons and neutral atoms or molecules, move, under the action of the high electric field, in the opposite direction. The inertia of ions being about 400 times that of electrons, their speed is slow as compared to the speed of electrons.

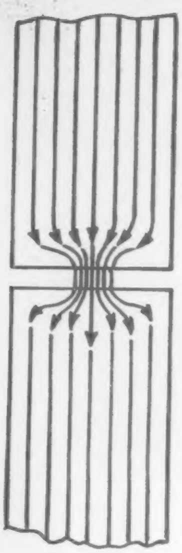
If it were possible to start a speedy separation of cooperating electrical contacts exactly at the moment of the passage of an alternating current through zero, arc initiation would not occur. So far as commercial power circuit breakers are concerned, an approximation to such synchronous operation has as yet only been achieved on $16\frac{2}{3}$ cycle, single phase circuits.

Obviously, the difficulties involved in effecting such synchronous interruption greatly increases when the system frequency is increased to 60 cycles per second. Still greater difficulties would be encountered in attempting to synchronize the operation of circuit interrupters in polyphase circuits, since this would involve separating cooperating pairs of contacts in the various phases of the circuit at different but coordinated points of time.

Synchronous operation of circuit interrupters is, therefore, impracticable based on means at present available. Consequently, circuit interruption by means of any commercial circuit interrupter results in an arc being drawn between the contacts.

II—PHYSICS OF A-C CIRCUIT INTERRUPTION

An electric arc at atmospheric pressure is composed of a thin, intensely luminous, extremely hot core which



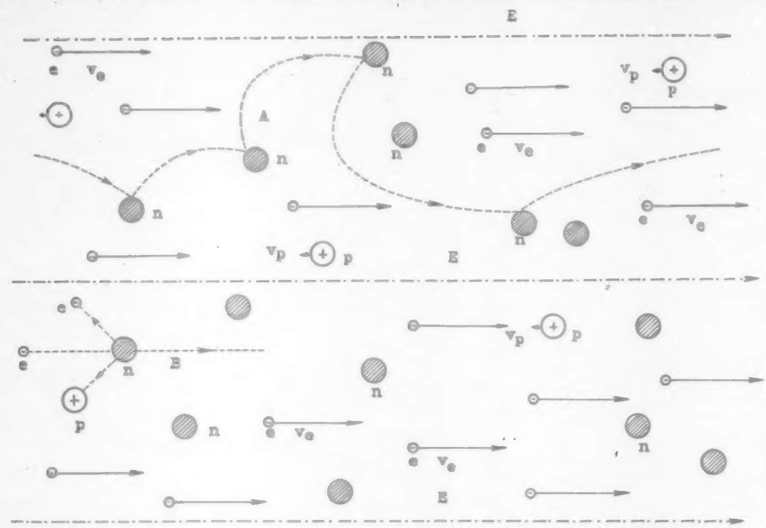


Fig. 1 (Left)— Concentration of current flow at the last point of contact after contact separation. Fig. 2 (above) — Electron and positive-ion currents in an electric arc. E — lines of force of electric field: e — electron; p — positive ion; n — neutral molecule; v_e and v_p — ave. speed of e and p in direction and opp. direction of E. A — trajectory of electron having elastic collisions. B — trajectory of electron having ionizing collision.

is surrounded by a zone of hot though relatively lower temperature gases. Certain factors tend to ionize the arc; others to deionize it. The state of equilibrium of an arc is defined by the equation:

Rate of ionization = Rate of deionization. Eq. (1)

The main factors which tend to ionize the arc are impact of electrons, accelerated by the electric field, upon neutral atoms; and thermal collision between neutral atoms. Thermal collisions between neutral atoms cause ionization when the neutral atoms collide at sufficiently high relative velocities to break up neutral atoms into electrons and positive ions, and such velocities occur at the high arc temperatures encountered in circuit interruption.

Deionization is achieved predominantly by re-combination, wherein an electron and a positive ion combine to form a neutral atom. Deionization may occur in space (called volume deionization), or in the presence of surfaces which favor deionization by surface action.

Where, in a given space, the ion concentration is not homogeneous, ions will flow from regions of relatively high to regions of relatively low concentration. This diffusion effect results in a deionization of regions of relatively high ion concentration and in increased ionization of regions of relatively low ion concentration. Similarly, turbulence will have a deionizing effect since it enhances re-combination.

Cooling reduces the kinetic energy of neutral atoms and, therefore, their impact upon one another, thereby restricting or eliminating thermal ionization.

Where the rate of deionization exceeds the rate of ionization, the arc will be extinguished after a certain period of time. In a-c circuits the arc current may decrease during any consecutive half cycle due to a continuing deionizing action. Under such circumstances, deionization of the arc path proper and of the arc zone, at any consecutive current zero, may have progressed somewhat farther than at the preceding current zero. After a certain number of consecutive current zeros, progressive deionization will have so reduced the conductivity of the path between the contacts that the impressed voltage will not be high enough to reestablish the arc after its natural extinction at the last consecutive current zero. Complete interruption of the circuit is then achieved.

If, in an ionized gas, a large number of electron-atom and atomic collisions is considered, an electric charge (an electron or ion) will have an average velocity v in the electric field which is determined by the equation:

$$v = K \cdot E \quad \text{Eq. (2)}$$

where K is a factor known as the mobility constant and E is the strength of the electric field. It follows from equation (2) that the mobility constant K of positive ions is the ratio of their average velocity (in centimeters per second) to the intensity of the electric field (in volts per centimeter). The mobility constant of ions depends upon the nature of the ionized gas and upon the gas pressure. The mobility constant of electrons K_e is much higher than that of ions. The electrons will, therefore, drift through the arc gap at an average speed which is much higher than the average speed of positive ions. Fig. 2 is a diagrammatic representation of the positive-ion current flowing in one direction and of the electron current flowing in the opposite direction.

Because of the low mobility of positive ions as compared to that of electrons, the part of the arc current derived from the flow of positive ions (known as convection current) is very small compared with the part derived from the flow of electrons (known as conduction current). Neglecting the positive-ion current, the current strength of the arc may be expressed by the equation:

$$I = n \cdot e \cdot K_e \cdot E_g \cdot \frac{\pi d^2}{4} \quad \text{Eq. (3)}$$

where

I = current in amperes,
n = number of free electrons per cubic centimeter,

$e = 1.59 \times 10^{-19}$ coulombs,

K_e = mobility constant of electrons in $\frac{\text{cm}}{\text{sec}} \Big/ \frac{\text{volts}}{\text{cm}}$

E_g = voltage gradient in $\frac{\text{volts}}{\text{cm}}$

d = diameter of the arc column in cm

Dividing Eq. (1) by l (arc length in centimeters) gives the conductance of the arc (the reciprocal of the arc resistance).

$$\frac{I}{E_g . l} = \frac{1}{l} \;.\; n \;.\; e \;.\; K_e \frac{\pi d^2}{4} \text{..............Eq. (4)}$$

Methods of circuit interruption

Equation (2) indicates three fundamental methods of interrupting a circuit by reducing the conductance of the arc path:

(1) By increasing its length l — known as circuit interruption by arc elongation. This method is extensively applied, though subject to various limitations. One important limitation is that complete high voltage circuit interruption requires extreme arc elongation, unless interruption is aided by other arc extinguishing factors.

(2) By reducing the diameter d of the arc core — known as circuit interruption by arc constriction. This method can be accomplished by such mechanical actions as squeezing, shearing, or pinching of the arc column. It is limited, however, by the fact that any solid material which, for the purpose of arc constriction, is brought into close contact with the arc, deteriorates rapidly owing to the high arc temperature. In spite of this limitation, circuit interruption by arc constriction is extensively applied, particularly in combination with other arc extinguishing means.

(3) By decreasing the number of free electrons per cubic centimeter. This method, combined with other arc extinguishing features, is applied in circuit interrupters which rely on a gas blast to achieve their purpose.

It follows from equation (3) that, with a given current I, the diameter d of the arc depends on both the number n of free electrons per cubic centimeter and the voltage gradient E_g. For a given current I, the diameter d of the arc core will vary inversely with the values of n and E_g. Arc extinction is facilitated when the arc is highly concentrated and of small diameter.

A quantitative investigation of the process of ionization and deionization in arcs moving through space within circuit interrupters is extremely difficult. Because of the extreme complexity of the problems involved, such investigations have not yet progressed very far and there is still considerable controversy among investigators of arc phenomena as to the evaluation of certain observations.

Arc energy

The ohmic resistance of a closed circuit interrupter is small; hence the I^2R losses are negligible and output is practically equal to input. When a circuit interrupter opens under overload or short-circuit conditions, owing to the magnitude of the current and of the arc resistance, a large amount of energy is released by the arc. Under the most unfavorable conditions there may be no appreciable output, all the input energy being converted into arc energy. A circuit interrupter opening under overload or short-circuit conditions must, therefore, be capable of dissipating this large excess of input over output energy.

In Fig. 3, G is a generator, one phase of which is connected to ground, CB a circuit breaker, F a feeder, and L a load center at the end of the feeder. Line l indicates the potential distribution prevailing along the above system, as long as it is intact. If a short-circuit occurs at S, the voltage at this point will be zero and the generator voltage will decrease a certain

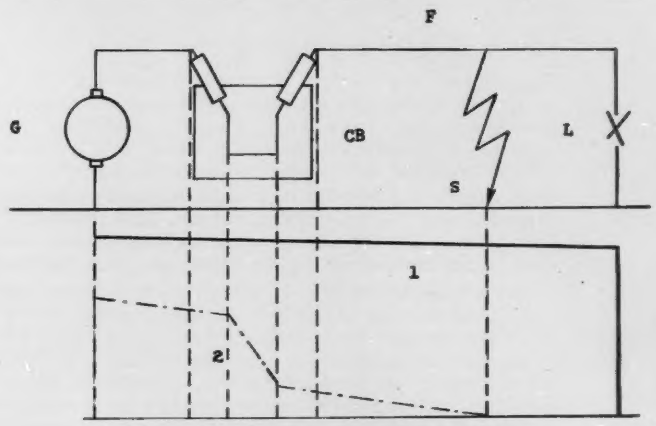


Fig. 3 — Potential distribution prevailing along a transmission line before and after a short-circuit.

G — generator
CB — circ. breaker
F — feeder L — load
S — short-circuit
1 — voltage distribution under normal conditions.
2 — voltage distribution, short-circuit conditions

percentage. When the circuit breaker CB opens, the major part of the reduced generator voltage will prevail between the separated contacts of the circuit breaker as shown in Fig. 3 by the dotted line 2 which indicates the voltage distribution under short-circuit conditions.

The total arc energy expended during the interrupting process may be determined either by recording arc voltage and arc current by means of an oscillograph, or by recording the total arc energy directly with a suitable ballistic wattmeter. In practice, the fact that the total arc energy is approximately proportional to the product of the current in the circuit just before contact separation, multiplied by the voltage across the contacts immediately after arc extinction, multiplied by the arcing time, is often used to approximately determine the total arc energy.

Arc energy dissipation

It is difficult to apportion the distribution of dissipation of the arc energy within an interrupter. Some energy is expended in heating the contacts and other

structural parts and in melting and vaporizing the contact metal. Energy is also expended in ionizing the arc column by collision. The electrons and ions derive their kinetic energy from the electric field which prevails between the contacts. The kinetic energy given up by the electrons and ions in collision with gas particles results in a high gas temperature within the arc column, thereby ultimately converting electrical energy into heat.

In oil circuit interrupters an appreciable amount of energy is expended in vaporizing and dissociating oil (at an average rate of 50 cm^3/kw second). Additional energy may be expended due to vaporized and dissociated oil causing displacement of the liquid oil, which, in turn, causes compression of the air between the surface of the oil and the oil tank cover. While it is possible to calculate some of the quantities of energy expended, it is not possible to fully apportion the total expenditure of arc energy.

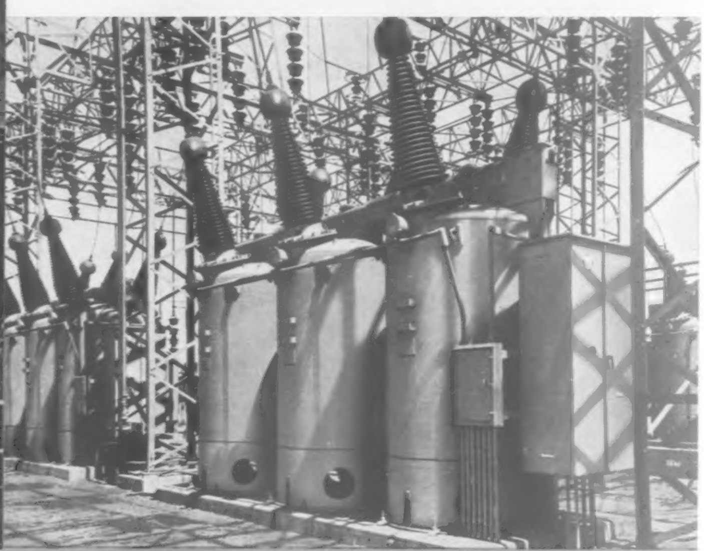
Limitation of arc energy

The higher the energy liberated within the interrupter the more difficult it is to dissipate it. Excessive energy may have harmful results, including destruction of the circuit interrupter. Hence, it is desirable to limit the arc energy to the fullest extent possible. Since the amount of energy released in an arc depends upon the arc voltage, the arc current and the arcing time, the arc energy may be kept within desired limits by controlling any of these three factors.

Arc elongation results in a higher arc voltage and consequently in an increase of the arc energy. It is, therefore, subject to limitations because of the need to restrict the arc energy. The use of blasts of fluid for deionizing the arc path makes it possible to effect complete interruption of power circuits at small arc gap lengths within half a cycle of the current wave. Therefore, certain fluid blast interrupters do not rely on arc elongation as a method of circuit interruption, nor does their use involve the release of large total arc energy within the interrupter.

The material of which the contacts are made, as well as their design, are factors determining the arcing time and consequently the total arc energy. Contacts having high specific heat, high heat-conductivity and high heat capacity will rapidly lose their thermionic emissivity and thus tend to inhibit reestablishment of the arc, to shorten the arcing time, and to limit the total arc energy.

Arcing causes loss of contact material through contact erosion, the amount lost depending, among other factors, on the total arc energy. Hence, limitation of the total arc energy results in increased contact life.



With an interrupting capacity of 2,500,000 kva, these outdoor oil circuit breakers in the switchyard of a military installation are rated 1,200 amperes, 161,000 volts.

Arc characteristics

Fig. 4 shows, diagrammatically, an oscillogram of an arc discharge. V is the line voltage, I the arc current, and U the arc voltage. The voltage u_r, or reignition voltage, is that required for re-igniting an arc after a current zero. The relatively constant voltage u_b is called the arc burning voltage. Arc extinction occurs at the elevated voltage u_e or extinguishing voltage.

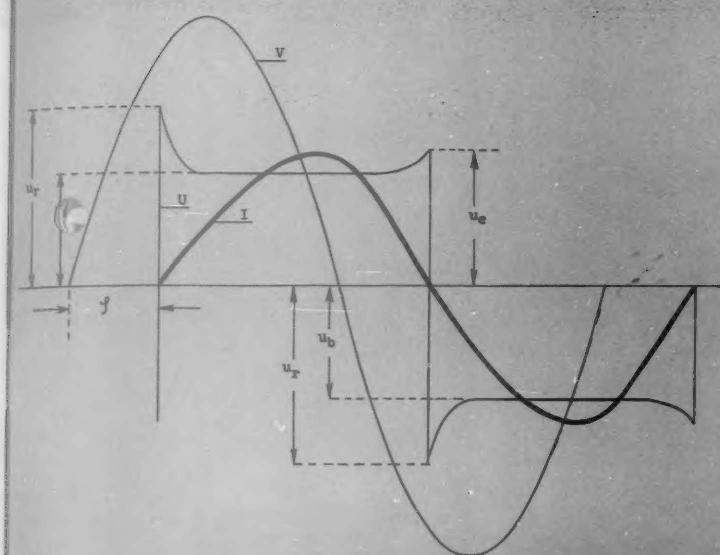
In Fig. 5, line S_a indicates the volt-ampere characteristic of a d-c arc and line S_d the volt-ampere characteristic of an a-c arc. Any arc has a negative characteristic; that is, the arc voltage decreases as the arc current increases, and vice versa. While this is true as to both a-c and d-c arcs, a-c arcs exhibit a "hysteresis" or "inertia" effect. During current zero, the path of the arc loses its conductivity owing to deionization and cooling and to failure of the circuit to replace the energy thus expended. Hence, an elevated voltage is required to re-establish the arc after current zero. The branch of the a-c volt ampere characteristic for increasing current lies above, and, for decreasing current, below the d-c volt ampere characteristic. This is indicative of the fact that in the former branch there is a deficiency, and in the latter branch an excess, of ionization relative to the ionization in the d-c current arc. At low currents, the burning voltage of the a-c arc rises again in accordance with that of the d-c arc. The average burning voltage U_b has been indicated in Fig. 5 by a horizontal line.

If the circuit contains a certain amount of resistance, in addition to the arc resistance, the voltage drop across both resistances may be added and plotted versus the arc current in a similar manner to that in which the arc voltage is plotted in Fig. 5. Since the circuit resistance voltage drop increases, but the arc voltage decreases, as the current increases, these two opposing tendencies tend to neutralize each other. They would, therefore, manifest themselves by a decrease of the curvature of the volt-ampere characteristic shown in Fig. 5.

Inductance, resistance effects

Considerating the interruption of an inductive circuit having no ohmic resistance, the current lags the applied voltage by 90 degrees. When the contacts of a circuit interrupter separate, arc resistance is inserted into the circuit. Since arc resistance is ohmic resistance, its insertion tends to decrease the lag of the current.

When an arc is elongated during the process of interruption of an inductive circuit, the consequent



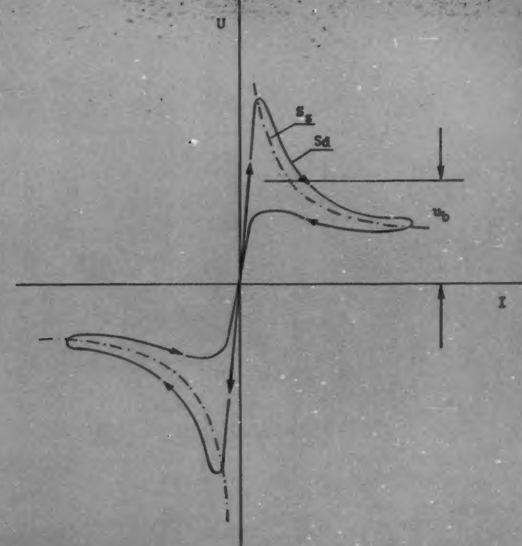


Fig. 4 — Line voltage, arc voltage and current plotted against time.
V — line voltage U — arc voltage u_r — reignition voltage
I — current being interrupted; u_b — burning voltage
phase angle u_e — extinction voltage

Fig. 5 — Volt-ampere characteristics of d-c and a-c arcs.
U, I — Coordinates voltage and current; S_d — volt-ampere characteristic, a-c arc
u_b — average arc-burning voltage; S_s — volt ampere characteristic, d-c arc

continuous increase of the arc resistance is accompanied by a continuous decrease of the phase angle between the circuit voltage and the current. Nevertheless, the phase angle between the voltage and the current cannot be reduced to zero by increasing the arc resistance by arc elongation, because current zero is always reached before the arc resistance reaches the value at which the phase angle would become zero.

In a circuit in which the resistance is relatively large, the shapes of the current and arc voltage waves immediately before and after current zero are such as to permit a more effective deionization and cooling during that period than in a circuit with relatively high inductance. Hence, the presence of resistance in an a-c circuit tends to facilitate its interruption.

Effect of deionizing effort

If, in a circuit interrupter, the deionizing effort is relatively weak, the rate of rise of the arc voltage will be relatively small and the voltage which, subsequent to the first current zero, is impressed upon the arc gap may be equal to the re-ignition voltage and thus cause re-establishment of the arc. If this occurs, the process will start anew. There is the difference, however, that, during the second half cycle, the rate of deionization is increased by reason of continued elongation of the arc. Consequently, deionization of the arc gap during the second current zero progresses farther than at the first current zero, and a higher re-ignition voltage is required to re-ignite the arc after the second half cycle. Hence, the conditions for achieving complete interruption have improved at the end of the second half cycle.

If arcing continues beyond the second half cycle, the voltage required for maintaining the arc continues to increase progressively by reason of further elongation and cooling. Consequently, the conditions for achieving complete interruption of the circuit become more and more favorable as arcing continues. Prolonged arcing, however, tends to raise the total arc energy, to shorten the life of the contacts, and may be conducive to system instability. It is, therefore, generally desirable to keep the arcing time within relatively narrow limits. In the case of power circuit breakers, it is often desirable for the arcing time not to exceed one-half cycle. Under special circumstances the deionizing effort may even be so increased as to cause arc extinction substantially prior to the first natural zero of the current wave.

A minimum deionizing effort will suffice for effecting permanent interruption of an a-c circuit if the effort occurs at the end of a half cycle when ionization of the arc path drops to its lowest value. Any deionizing effort exerted prior to a natural zero of the current wave will result in an increase of the arc voltage and of the arc energy in proportion to the magnitude of the deionizing effort. The greater the deionizing effort, the sooner the flow of current will cease prior to a natural zero of the current wave.

Circuit interruption at current zero

When an a-c circuit is interrupted about the time of a natural passage of the current through zero, the arc energy does not comprise any appreciable amount of magnetic energy because the energy stored in the magnetic field of the electric system at that time is small. But, where an a-c circuit is broken at a time considerably before a natural current zero, entailing drastic forcing of current zero, the more or less considerable magnetic energy stored in the circuit must be dissipated in the form of increased arc energy.

Hence, most a-c circuit interrupting devices are designed to effect interruption substantially at a natural current zero.

The relation between circuit and circuit interrupter, as well as design principles of circuit interrupters, will be dealt with in succeeding parts of Dr. Salzer's article, to appear in the A-C Electrical Review.

DON'T LOSE YOUR BEARINGS!

These tips on proper maintenance and inspection care show how to lengthen motor and generator life by avoiding insulation and bearing failures, most common breakdowns in rotating machines.

G. L. Ringland

ENGINEER-IN-CHARGE, NORWOOD MOTOR SECTION • ALLIS-CHALMERS MANUFACTURING COMPANY

● Since insulation and bearings are perishable elements in an electrical machine, most of the troubles encountered in the use of motors or generators center around one or the other. Consequently, proper maintenance and inspection can greatly lengthen the life of a rotating machine by preventing bearing or insulation failures which often result in serious damage to other parts.

Reports on unsatisfactory bearing operation many times state that the bearing is operating at a temperature too hot for the hand to endure. When we consider that even a temperature of 50 C is painful to most people, and that normal temperatures up to 90 C are permissible, it is obvious that the sense of touch is not a proper method of measurement. Bearings would develop some temperature above that of the room in which they operate, even if their losses were zero, as heat is conducted to them through the shaft. The operating temperature of the bearing is the sum of the air temperature, the temperature due to conducted heat, and an additional increment of temperature due to the friction losses of the bearing itself.

One type of "trouble" frequently reported results from the fact that the front bearing of a motor operates at a higher temperature than the rear bearing. This, however, is a normal condition since the shaft extension carries away some of the bearing heat at the rear end, while the front end, which has no shaft extension, disperses its heat less efficiently.

Overgreasing causes overheating

The most common cause of high temperature in a ball bearing is too much grease. Motor manufacturers attach standard instructions to every ball bearing motor when it is shipped, and motor users are continuously warned against filling a ball bearing cavity full of grease. In spite of this, an over-conscientious maintenance man will add grease to ball bearings on a schedule, which results not only in the bearing cavity becoming stuffed with grease, but it may also force grease into the interior of the motor. Grease within a ball bearing cavity should not be continuously churned by the operation of the bearing. If there is sufficient space for the bearing to run free, it will clear a channel for itself, and operate with very low friction losses, and at a low temperature, obtaining its lubrication from the capillary flow of oil from the grease along the adjacent surfaces. The grease itself will occupy the space within the bearing caps without continually flowing into the bearing.

If the outer cap is removed after a ball bearing has been operating normally for some time, it will be seen that the grease which comes away with the cap is nearly as firm and solid as it was in the original container. The thin semi-liquid oily film covering the bearing provides proper lubrication which may last as long as two years or more without renewal. This ideal is apt to be prevented, however, by frequent additions of grease. It is much better to allow ball bearings to operate at least two months at a time

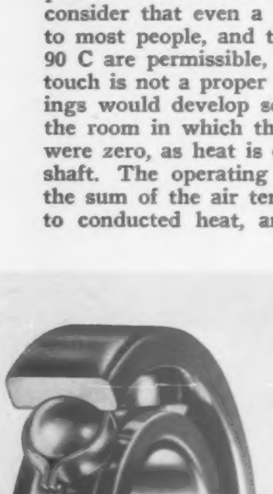


Fig. 1 — Ball bearings can take tremendous momentary overloads without injury and are ideally suited to general purpose service.

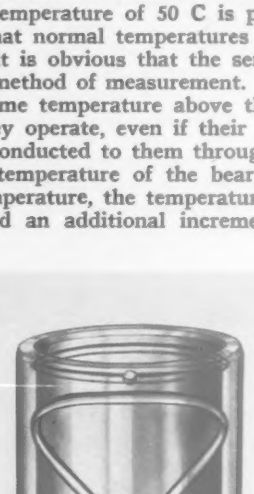


Fig. 2 — Sleeve bearings must be protected for radial loads. This figure "8" grooving affords best oil distribution and extra cooling effect.

AT RIGHT: Drilling low pressure cylinder horizontal flange of cross-compound main propulsion steam turbine for a Victory ship of the U. S. Merchant Marine.


CARLTON

with no attention whatever, and then when they are serviced, an inspection of the condition of the grease in the outside caps will indicate whether or not additional grease should be added. The outside caps can be removed for this inspection, or they can be inspected by merely shining a flashlight into the pipe plug opening in the cap.

The treatment for a very hot ball bearing is obviously to remove a large amount of grease from the bearing cavity, and to permit the motor to stand idle until the temperature is reduced to a point which allows the remaining grease in the bearing to solidify. Usually when this is done, the bearing will again operate continuously at its normal mild temperature.

The best grease for ball bearing operation is compounded from a soda base, has a fibrous or granular texture, and becomes liquid only at a temperature well above 100 C.

Excess grease can damage a bearing also by preventing the balls from turning immediately when a cold motor is started. A film of hard grease between the balls and the retainer holds the balls stationary for a moment, causing them to slide on the raceways of the bearing, and producing what ball bearing manufacturers call "smearing." This results in minute flat spots on the balls, and roughened tracks in the raceways. After this has once occurred, increasing roughness and eventual failure are the result. Roughness and a grating noise gives ample warning of this condition and such a bearing should be replaced before further damage to the motor results.

Ball bearing mounting

The mounting of a ball bearing on a motor shaft must always provide for some degree of tightness of the inside race of the bearing. This tightness can vary only over a limited range, but machining tolerances are such that, with a minimum size bearing seat on the shaft and a maximum bore in the bearing, the press fit will be as much as .0001 of an inch. Conversely the maximum tightness, which results from a combination of minimum bore and maximum diameter of shaft, must not be enough to pinch the balls of the bearing by expansion of the inside race. This amount is from .0006 of an inch on small bearings to as much as .002 of an inch on large bearings.

In specifying the bore of the housing to contain the outside race of the bearing, the ideal condition is practically the opposite. Best results will be obtained if the outside race is a sliding fit in the housing bore or, in large bearings, as much as .003 of an inch clearance. This method of mounting provides an allowance for expansion of the bearing materials under normal heat, and prevents the housing from impressing upon the bearing whatever out-of-roundness exists due to strains or imperfect machining. The quantities involved are very minute, but in general, success of ball bearings depends as much upon precise workmanship in mounting the bearings as on the quality of the bearing itself.

Failure of a ball bearing due to looseness on the shaft requires replacement of both shaft and bearing, and frequently failure of a bearing due to tightness of the outside race in the housing bore also involves damage to the housing as well as to the bearing.

Sleeve bearing problem

The design of sleeve bearings involves problems that are quite different from those that are encountered in the use of ball bearings. The latter are capable of taking tremendous momentary overloads without injury, and are, therefore, ideally suited to general purpose service where the peculiarities of the application are not known when the motor is built.

In sleeve bearing motors it is necessary to protect against damage to the bearing under a radial load in any direction from horizontal to vertical for belted or geared drives, and to maintain adequate capacity under these loads. Also, the sleeve bearing should

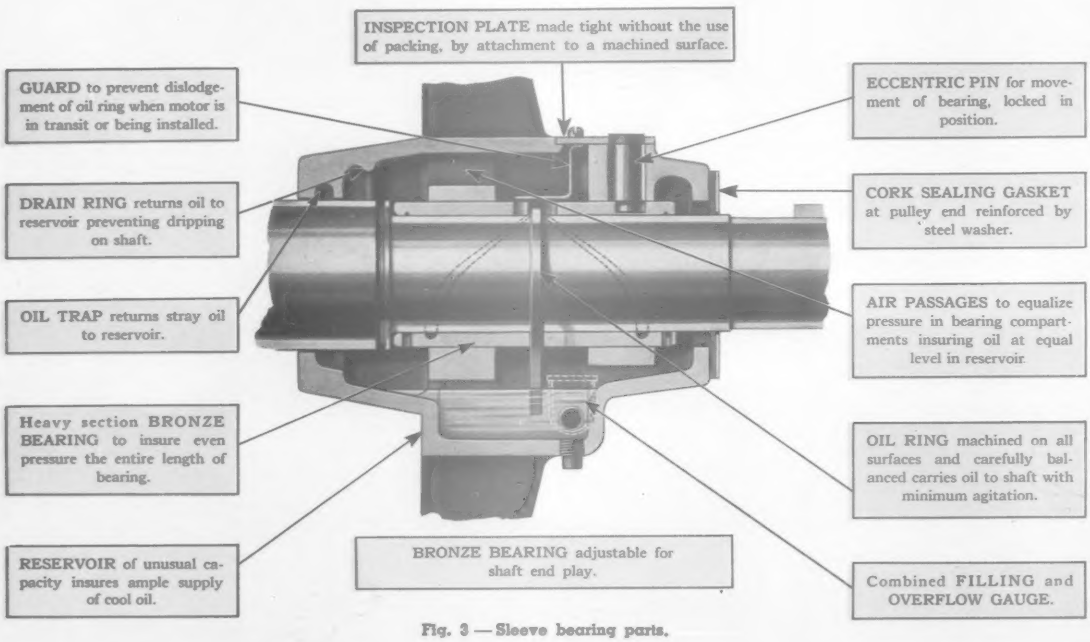


Fig. 3 — Sleeve bearing parts.

Fig. 4 — (l. to r.) Solid babbitted bushing, split babbitted bushing, ball bearing and bronze bushing.

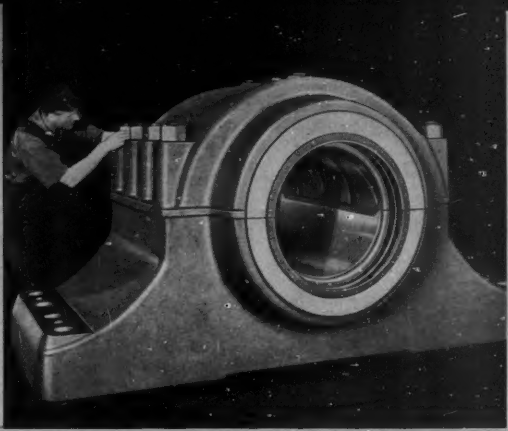


Fig. 5 — Large thrust-type pedestal bearing.

be able to carry a mild thrust load and the maximum torque of the motor during starting, even though this flexes the shaft slightly at the moment when the maximum torque occurs. These requirements can be met in manufacture only by careful attention to materials used, machining, oil distribution system, and bearing proportions.

The grooving of the bearing bushing for oil distribution must be such as to leave large film areas for sustaining pressure with any direction of radial load. Such grooving is best accomplished by distributing from the top center of the oil ring slot by grooves which form an "X" in the top of the bushing, or a figure "8." In both cases the bearing surfaces should be relieved around the center of the "X," so that oil will be pushed sidewise into the grooves by the weight of the oil ring. The figure "8" groove has the additional advantage of allowing the oil to circulate, which provides some cooling effect in addition to its lubricating function. Drain grooves at both ends of the bushing serve to collect the film oil and return it to the oil well in liquid form without throwing it off in the form of spray. This oil is normally drained from a small hole at the bottom of the drain groove. In small size bushings the size of this drain hole may be made merely enough to relieve pressure, or omitted entirely. The latter provision will allow some oil to flow over the end of the bushing to lubricate the thrust surface in case some thrust load is present.

Deflection considerations

Sleeve bearing diameters are related in some degree to the standardized diameters of motor shaft extensions as set up by NEMA. In general, a bearing 1/8 of an inch larger than the standard shaft extension diameter would carry a V-belt or flat belt load as high as the shaft deflection will permit. In other words, the flexing of the shaft under the load of the belt pull reaches its limit at a lower load than the oil film pressure does. Shaft deflection is permissible up to the point where the oil film at the outer end of the bushing breaks down under the concentrated pressure. Deflection beyond that point results in the shaft reaming out the end of the bearing, depositing metal in the oil, and rendering the bushing unfit for further use. This flexing of the shaft limits the load capacity of the bearing to a greater degree when the bushing is long in comparison to its diameter. Designers have recognized this in recent years, and the design practice at the present time is to reduce the ratio of length to inside diameter. This ratio can be 2 to 1, 1½ to 1, or even 1 to 1 compared with former proportions of 3 to 1 and 2½ to 1.

The shortness of the bushing not only helps the operation under a condition of shaft deflection, but it also allows a small amount of self-alignment in the mounting of the bearing, provided the fit of the bushing in the housing bore is not too tight, and the seat somewhat short. It is common practice to fit the bushing into the housing bore with a very light tapping fit, or even a sliding fit. Often such a bushing can be replaced without removing the end bells of the motor, and in case of severe overheating there is less tendency for the bearing to freeze. On motors using V-belt drives a sleeve bearing motor will often knock back and forth in its end play, producing a disagreeable hammering which is quite difficult to correct. This condition may be due to load pulsations, to individual differences in the V-belts, or a combination of both. Some motor manufacturers prefer to use large end play so that the oscillation of the rotor shaftwise does not cause bumping against the shoulders. Others prefer to limit the end play to a small amount, such as .010 if an inch to .030 of an inch, providing at the same time enough thrust capacity to allow actual rubbing. Either of these methods is effective. If adjustment of the end play is provided in the motor, it is still more effective to reduce the end play to a minimum.

Materials used in bushings

The material of the bushing can be either bronze or babbitt. Bronze bushings must have sufficient strength to maintain their shape when supported by a limited outside area, so that the metal must have high strength as well as the necessary grain structure required by bearing metal. Bronze which has a moderately high tin content and a smaller percentage of lead is ideal. A common formula is 80 percent copper, 10 percent tin, and 10 percent lead. This type of bearing bronze is also available in combination with a cheaper and stronger metal in the form of bimetal sheets. These are largely used on small fractional horsepower motors. Bushings of steel or cast iron tubing with babbitt linings, often centrifugally applied, are also in general use for the same class of service as the cast bronze bearings. In larger sizes, heavy walled shells of cast iron with anchored linings of babbitt are best suited. Such babbitt may have a

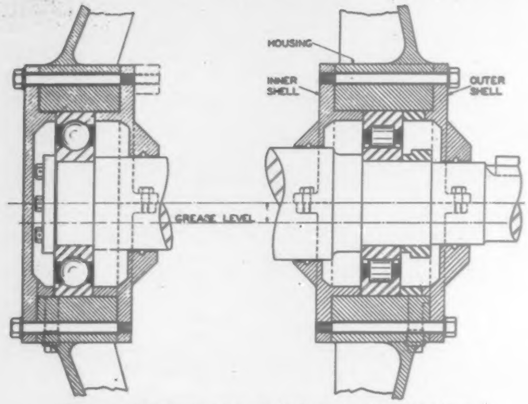


Fig. 6 — Sectional view of ball and roller bearings.

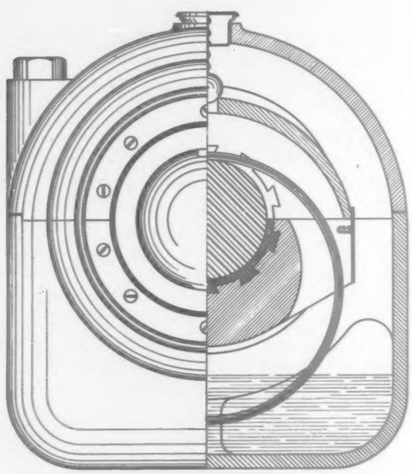


Fig. 7 — End view of this sleeve bearing shows that the oil ring is completely enclosed in the bushing (except for a short distance above the oil surface) to prevent the rings from spraying oil against housing walls.

very high tin content to provide strength against excessive pressures, and high impact, or a lead babbitt which, while lacking the strength of the tin babbitt, becomes permanently seated to the journal surface very quickly under normal load conditions and operates successfully for a very long time.

Larger motors at 1,800 and 3,600 rpm are designed for direct connection only, and it is often considered that the bearings on these are required to support only the weight of the rotating element. It should be kept in mind, however, that flexible couplings do not correct misalignment, and that inaccurate application of such motors to their loads can result in very excessive bearing loads which can destroy the bearings before the condition is apparent. Many types of couplings also tend to spread when load is applied, and the shaftwise component of the torque pushes the motor rotor against the shoulder of the opposite bearing. This results in overheating and short life. Such trouble has become so common that coupling manufacturers, in many cases, have devised means in the assembly of their couplings to limit the spread to a value which does not allow the motor bearings to be burdened in this manner.

Compared with the bearings of many other machines, electric motor bearings are subjected to much more exacting service, so that proper care and maintenance will pay correspondingly higher dividends in the long run.

Wound Rotor Motor Starters For General Purpose Duty

Recently introduced is a new series of wound rotor motor starters constituting a complete line of magnetic primary and secondary controllers in ratings from 5 hp at 220 volts to 1,000 hp at 4500 volts. They are designed for starting duty only and are of both non-reversing and reversing types.

Known as Type ALW, the new starters are designed for general purpose applications with motors for driving pumps, fans, compressors, conveyors, crushers, etc. Approximately 150 percent full load motor torque and current are obtained on the first point of acceleration. For high inertia loads an additional accelerating contactor can be furnished.

All of the new type ALW starters are rated 3-phase, 60 or 50 cycles, the interrupting capacity being 10 times motor full load current. They provide automatic, magnetic, adjustable time-delay acceleration, thermal overload and instantaneous undervoltage protection. Pressing the "start" button closes the line or primary contactor and connects the motor to the line with all secondary resistance in the circuit. Secondary contactors close in timed sequence until the starting resistor is completely cut out by the final accelerating contactor.

New Drum Controller Is Cam Type

For controlling secondary circuits of wound rotor induction motors on pumps, blowers, crushers, kilns, and similar non-reversing applications, a newly designed manual drum (Type 5852) is now being used extensively. In applications of the new unit a separate starter is required for primary control.

Compact cam mechanism of the new drum is easy to operate and uses larger contact tips. Perfect contact alignment assures cooler running and longer life, while ample wiping action keeps contacts clean.

Built for long, heavy-duty use, the new drum controllers have a sturdy, welded steel frame and a heavy sheet steel cover, classed as a NEMA Type 1 general purpose enclosure.

For further, more detailed information regarding these new products, write the Editors of ELECTRICAL REVIEW.